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Review

Filtration performance characteristics of ceramic candle filter based on inlet structure of high-temperature and high-pressure dust collectors

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ABSTRACT

We fabricated and compared two high-temperature and high-pressure dust collector models: the conventional direct inlet model, where a round gas inlet pipe is connected to the bottom of the collector at a right angle; and the inertial inlet model, where a rectangular gas inlet pipe is tangentially connected. Their effects on the filtration performance of a ceramic candle filter were tested at 800 °C and 3 atm and compared. The inertial inlet model showed a slower increase in pressure drop as the filtering process progressed owing to the reduced dust load on the filter. The average cleaning interval was 4–7 times longer than that of the direct inlet model. The residual pressure drop increased in direct proportion to the filtration velocity and was about twice that of the inertial inlet model. The inertial inlet maintained a higher cleaning efficiency during operation than the direct inlet. The overall collection efficiency was over 99.999% with the inertial inlet model, allowing for slight variations according to the filtration velocity, and that of the direct inlet method was over 99.9% under the same conditions.

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Nomenclature

a	height of inertial inlet (mm)
b	width of inertial inlet (mm)
C_i	inlet dust concentration (g/Sm^3)
D_I	diameter of inner tube (mm)
D_R	diameter of body (mm)
d_i	diameter of direct inlet (mm)
H_I	height of inner tube (mm)
P	inlet hot air pressure (Pa)
P_P	pulse air pressure (Pa)
P_D	pulse duration (ms)
T	inlet hot air temperature (°C)
V_f	filtration velocity (m/min)

Introduction

About 90% of high temperature and high pressure (HTHP) dust collection systems currently used around the world – such as the integrated gasification combined cycle (IGCC) power system, pressurized fluidized bed combustion (PFBC) power system, and synthetic natural gas manufacturing process – use ceramic candle filters. The remaining 10% use metal filters. Ceramic filters demonstrate nearly 100% fly ash removal efficiency and have high thermal, chemical, and mechanical resistance, which makes them suitable for applications associated with high temperature (up to 1000 °C) and high pressure (15 atm) conditions [1,2].

PFBC and IGCC power systems operate under temperatures of up to 850 °C and 250–400 °C, respectively, and pressures of 1–1.2 and 8 MPa, respectively. Many studies have attempted to simplify the HTHP filtering processes while increasing energy efficiency, removing as much fly ash as possible, and reducing the overall operating costs [3].

Owing to its integration of the gasification system in the combined cycle, IGCC is a next-generation thermal power plant technique that is highly efficient and eco-friendly compared to its predecessors. Besides power generation, the coal-gasification technique can produce synthetic gas, hydrogen, liquefied petroleum gas, and a wide variety of chemical products. It can serve as a base technology for use in conjunction with future energy technologies such as industrialized hydrogen and fuel cells. An IGCC power system mainly comprises an air separation unit, gasification unit, and combined cycle unit. The air separation unit separates nitrogen and oxygen from the air and supplies them to the gasification and combined cycle units. The gasification unit initiates the gasification process in the gasifier using coal, oxygen, and steam in order to produce synthetic gas as HTHP combustible fuel; fly ash and sulfurous components are removed by passing the gas through dust collection and desulfurization systems. The purified synthetic gas drives the gas and steam turbines of the combined cycle to generate power. While general coal-fired power plants only have to meet environmental standards for fly ash emissions, the IGCC power system requires the purified synthetic gas supply to have a fly ash removal rate of over 99.9% to protect the desulfurization system and gas turbine and to ensure safe and stable operation [4].

The tangential flow filtration method is a new technique in which dusty gas is transferred parallel to the filter surface; this is in contrast to the conventional normal flow filtration method, where dusty gas is loaded perpendicular to the filter surface. The characteristics of the tangential flow filtration method are quasi clogging-free fly ash collection on the filter surface and low pressure drops even at high filtration velocities. Moreover, the pressure drop increases slowly owing to the smaller amount of dust adhering to the filter, and the cleaning frequency is reduced, which leads to longer cleaning intervals and ultimately prolongs the service life of the filter. However, related research has only been conducted at the laboratory scale so far [5–7].

In this study, our objectives were to prolong the service life for the HTHP dust filter of an HTHP dust collector by reducing its dust load, reduce system operation costs by maintaining a slow increase in the pressure drop of the device and improving the cleaning efficacy, and ensure the safety of the device design technique. We fabricated two models: one using the conventional direct inlet method, where dusty gas is introduced to the HTHP collector through a cylindrical inlet connected perpendicularly to the device bottom; and the other using the inertial inlet method, where a rectangular inlet pipe is connected tangentially to the device bottom. We compared and analyzed the effects of these HTHP dusty gas inlet methods on the filtration performance of a ceramic candle filter by operating them under the conditions of 800 °C and 3 atm.

Test device and methods

Test HTHP dust filter

For the test HTHP dust filter, we used a ceramic candle filter (DSL Type 10-20, Dia-Schumalith, Germany) with a very stable physical structure and high mechanical strength. The filter employs a double-layer structure consisting of a substrate and membrane layers; the substrate layer is composed of silicon carbide, and the membrane layer is composed of mullite. Table 1 outlines the physical properties of the test ceramic candle filter.

Test dust

We produced five types of test dust (JIS Z 8901-1984) by pulverizing and classifying the coal fly ash of pulverized coal combustion obtained from the dust collector of a coal-fired power plant using a jet mill (Alpine Jet Mill AFG). Fig. 1 shows the dust particle size distribution, which was measured with a particle size measuring device (TSI, Particle Size Distribution Analyzer, Model 3603). The density of the test dust was approximately 1.17 g/cm^3, and its mass mean diameter was 14.7 μm. Fig. 2 shows a scanning electron microscopy (SEM) image of the test dust magnified 2000 times.

Gas inlet shapes of the test device

In order to compare and evaluate the filtration performance properties according to the structural variations of the gas inlet part of the ceramic candle filter, we fabricated two types of gas inlets with different structures and installed them in the HTHP dust collector. The first was an inertial inlet, which is rectangular in shape and has a cyclone; the second was a direct inlet, which is cylindrical in shape and has no cyclone. Fig. 3(a) and (b) shows the bottom parts of the inertial and direct inlets, respectively.

The inertial inlet structure was designed at an inlet width-to-length ratio (b/a) of 0.5 in order to maintain an optimal inlet

Table 1
Physical properties of test ceramic candle filter.

Material density	1.85 g/cm^3
Specific permeability	55×10^{-13} m^2
Maximum temperature resistance	1000 °C
Thermal conductivity	2.5 W/(m K)
Dimensions (Do/Di)	60/40 mm