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Development of Simulation System for Hot Gas Filtration by Ceramic Candle Filters on High Temperature and/or High Pressure Conditions

Key Words: Gas Filtration, High Temperature, High Pressure, Ceramic Candle Filter

Introduction

Hot gas filtration from industrial processes offers various advantages in terms of improvement of process efficiencies, heat recovery and protection of plant installation. Especially hot gas filtration is an essential technology for pressurized fluidized bed combustion (PFBC) and integrated gasification combined cycle (IGCC) promising coal-fired generation of electricity with substantially greater thermodynamic efficiencies and reduced particulate pollutant emissions.[(1)-(7)] The filtration protects gas turbine blades from the erosion and corrosion due to particulate matter and improves the performance of a heat exchanger connected to a steam turbine by decreasing particle deposition. Since these systems are operated at high temperature (600 – 900 ℃) and high pressure (6 – 10 atm) conditions,[(8)] high temperature and high pressure resistant materials are required. To meet these requirements, ceramic materials have been studied for applications in hot gas filters. Among the ceramic filters, it is known that silicon carbide is resistant to high temperature as well as high pressure.[(9)] Ceramic filters of candle type are commercially used for PFBC or IGCC systems. [(3), (7), (10)] Candle filters are hollow cylinders (closed on one end) typically with a diameter of about 6 cm and a length of 1 – 1.5 m, and with the wall thickness varying between 0.8 and 1.5 cm. An industrial filter vessel normally contains a large number of candle filters. Groups of candle filters are periodically cleaned by a back pulse jet flow to remove the dust cake collected on filter surfaces.

A number of hot gas filtration systems were developed and tested in the past. Reviews of gas cleaning at high temperatures including candle filters were provided by Thamimuthu[(11)] and Clift and Seville[(12)]. The candle filters generally have very high filtration efficiency of the order of 99.8%. There are, however, a number of unresolved problems with buildup of dust cake on the filters, occasional filter-ash bridging and filter failure and breakage.

Objective

In the present study, an experimental simulation system using indirectly preheated air has been developed to evaluate the performance of hot gas filtration. The experiments were performed at different operating temperature and pressure and filtration face velocity. Long-run operation of hot gas filtration on the conditions of high temperatures and high pressures has been performed stably and safely for future application of the hot gas filtration system to a clean coal technology system.

Project Description

Figure 1 shows the schematic diagram of the experimental system. The compressed air is supplied with a specific pressure by a compressor. A hot gas generator heats up the air indirectly and an electrical heater keeps the air temperature. The dusty air, mixed with particles fed by a dust feeder, enters a filter vessel through an inlet at the upper center region of the vessel. Adjusting the rotation speed of feed screw controls the feeding amount of particles. Four ceramic candle filters are installed in the vessel. The filters separate aerosol particles from the dusty air, then clean air is exhausted onto environment through a cooler, valves and a silencer. Particles collected on the filters are removed by back pulse jet flow and deposited into a hopper by gravitational sedimentation. The system is designed operated by 800 ℃, 15 kgf/cm2, and 800 SCMH in temperature, pressure, and flow rate. The filtration area is 0.375 m^2.

The porous candle filter is made of silicon carbide (SiC) powder of mean particle size 180 μm as support substrate and 22 μm as coated layer. The support substrate is made by cold isostatic pressing (CIP) and the coated layer by spray injection of powder slurry. The forming pressure of CIP is 400 kg/cm^2. The porosity of filter media is 33 % and the bulk density is 2 g/cm^3. The mechanical strength is 30 MPa measured by O-ring tests. The support substrate is for the mechanical strength of a filter and the coated layer for the surface filtration of fine particles.

Results

The fly ash of a power plant of coal fluidized bed combustion (CFBC) has been used as a test dust. The mean size of fly ash particles is 2.04 μm and standard deviation is 1.93. The material density of particles is 2.2 g/cm^3. The system has been operated at the conditions as shown in Table 1. The temperature in the filter vessel is 500, 600 and 650 ℃ and pressure is 5 and 6 kg/cm^2. The mean face velocity on the filter surface is 5 and 6 cm/s. The back pulsing is occurred when the pressure drop across the filter media and deposited dust layer approaches 800, 900, 1100 and 1200 mmH_2O. The pressure of a back pulsejet is 5 kg/cm^2 higher than the pressure inside the filter vessel. The duration time the back pulse nozzle is opened for is 100 msec. The particle concentration at the inlet of the vessel is 6 g/m^3.

Figure 2 shows the variations of pressure drops along the operating time of filtration. The initial pressure drop of clean filters is about 400 mmH_2O at temperature of 500 ℃, pressure of 5 kg/cm^2, and face velocity of 5 cm/s. The pressure drop increases as particles are collected onto the filter surfaces because the dust cake of particles plays a role of additional porous media. When the pressure drop approaches 800 mmH_2O, the filters are cleaned by back pulsejet and the pressure drop is reduced near the initial. However, the particles collected on the filters are not removed completely and some ones are remained on the filters, so that the pressure drop is not recovered to the initial. That is, there is a residual pressure drop right after filter cleaning by back pulsing. This is because fine particles collected deeply into filter pores are not easily detached by back pulsing. The residual pressure drop increases as the back pulsing is repeated and becomes above 500 mmH_2O at 50 hours. The experimental condition is changed to temperature of 600 ℃, pressure of 6 kg/cm^2 and back pulsing onset pressure drop of 900 mmH_2O after 50 hours in operating time. The residual pressure drop is 600 mmH_2O at 100 hours and above 600 mmH_2O at 150 hours. The residual pressure drop increases about 100 mmH_2O for 100 hours. This is because the gas viscosity and the slip effect of particles through filter pores due to longer gas mean free path increase with the increased temperature. When the temperature in the vessel is 650 ℃, the pressure is 6 kg/cm2, face velocity is 6 cm/s, and the back pulsing onset pressure drop is 1100 mmH_2O , however, the pressure drop increases more rapidly than before. This is because the pressure drop and the formation of dust cakes depends on the face velocity. The time derivatives of the pressure drop due to the dust cake forming on filter surfaces have been know proportional to the amount of particle loadings and the square of a face velocity.[(13), (14)] The pressure drop increases above 200 mmH_2O for 40 hours at that condition. When the back pulsing onset pressure drop is set 1200 mmH2O, the residual pressure drop is above 1100 mmH2O even thought the operating time does not pass by 10 hours.

Figure 3 shows residual pressure drops along the filtration time. The pressure drop keeps 530 mmH2O stably after 20 hours in operating time at the conditions that the temperature is 500 ℃, the pressure is 5 kg/cm^2, and the face velocity is 5 cm/s. Figure 4 shows residual pressure drop along the number of cleaning by back pulsejet. The residual pressure drop increases rapidly when the face velocity is 6 cm/s because particles are collected deeply on filter pores and does not detached easily by back pulse cleaning. Therefore, the back pulsing interval is shorter, so that the more number of back pulse cleaning should be performed. That results in the shortness of filter life time or the breakage.

Consequently, the pressure drop increases as face velocity increases. The pressure drop increases as particles are loaded onto filters. The filter cleaning is performed when the pressure drop approaches a limited value. The dust layer on the filter surface is not completely removed by the back pulsing and some dust particles are rested on filter surfaces. The residual dust particles occurs residual pressure drop. The filter cleaning efficiency by back-pulse jet decreases as face velocity increases because the particle are collected deeply into filter media. Therefore, the residual pressure drop increase with increasing face velocity. Through additional experiments, it was confirmed that the cleaning efficiency of filters increases with increasing the porosity of support layer of filter since the more kinetic energy of back pulse jet is transported as the filter porosity of support layer increases. The fractional filtration efficiencies are above 99.9 %. The efficiency increases as the thickness of the dust layer on the filter surface increases because the dust layer plays the role of a filter itself.

Application

The hot gas filtration system has been developed for simulation experiment. The dusty air is cleaned with ceramic candle filters. The simulation experimental system may be connected to a clean coal technology system or conventional industrial hot gas emission plants.

Future Activities

The future activities using our simulation experimental system are as follows:

- Direct use of hot gas emitted from a new developed burner using liquid fuel injection in the high pressure condition
- Studies about collection efficiencies and cleaning performance at different operating conditions such as pressures, temperatures, face velocities, and gas chemical

components.

- Studies about collection efficiencies and cleaning performance at different mechanical characteristics of filters such as the pore sizes of support substrates and/or surface layer, the permeabilities, the shapes of filter media.

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Table 1. Experimental conditions.

Operating parameter	condition
Temperature	500, 600, 650 ℃
Pressure	5, 6 kg/cm^2
Face velocity	5, 6 cm/s
Back pulsing onset pressure drop	800, 900, 1100,1200 mmH_2O
Back pulse pressure	10, 11 kg/cm^2
Back pulse duration time	100 msec
Inlet dust concentration	6 g/m^3

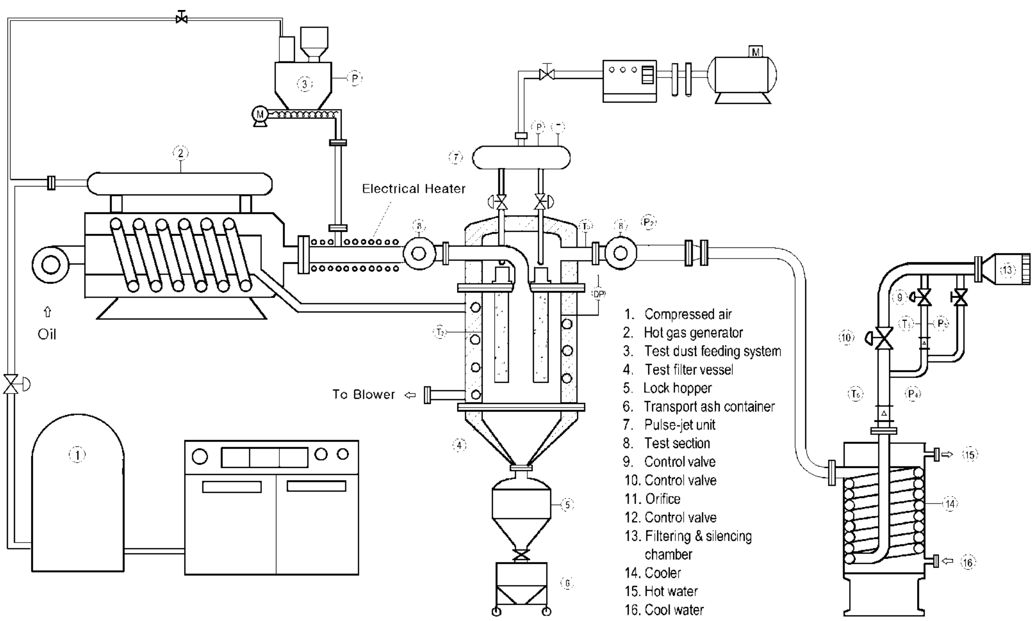

Figure 1. Schematic diagram of experimental system.

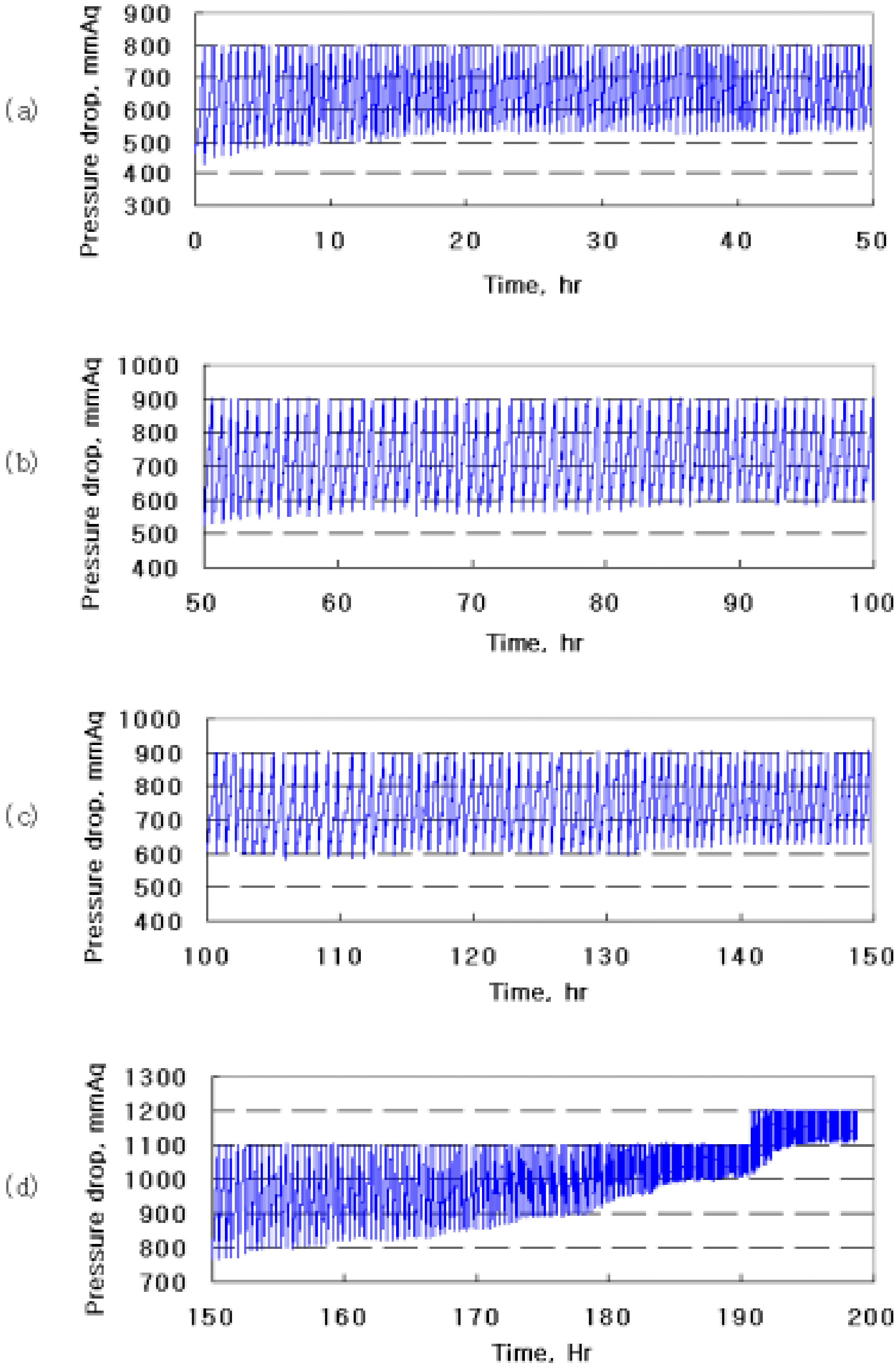

Figure 2. Variations of pressure drop along the filtration time;

(a) T = 500 ^{o}C, P = 5 kg/cm2, V_f = 5 cm/s, dP = 800 mmAq,

(b), (c) T = 600 ^{o}C, P = 6 kg/cm2, V_f = 5 cm/s, dP = 900 mmAq,

(d) T = 650 ^{o}C, P = 6 kg/cm2, V_f = 6 cm/s, dP = 1100, 1200 mmAq.

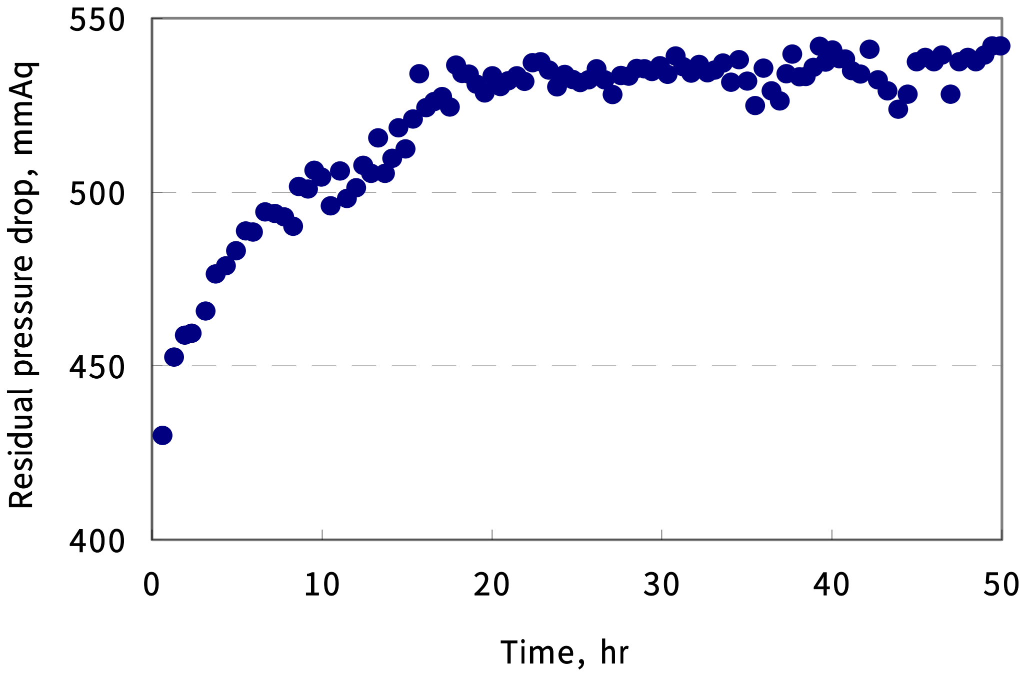

Figure 3. Residual pressure drop along the filtration time by 50 hours.

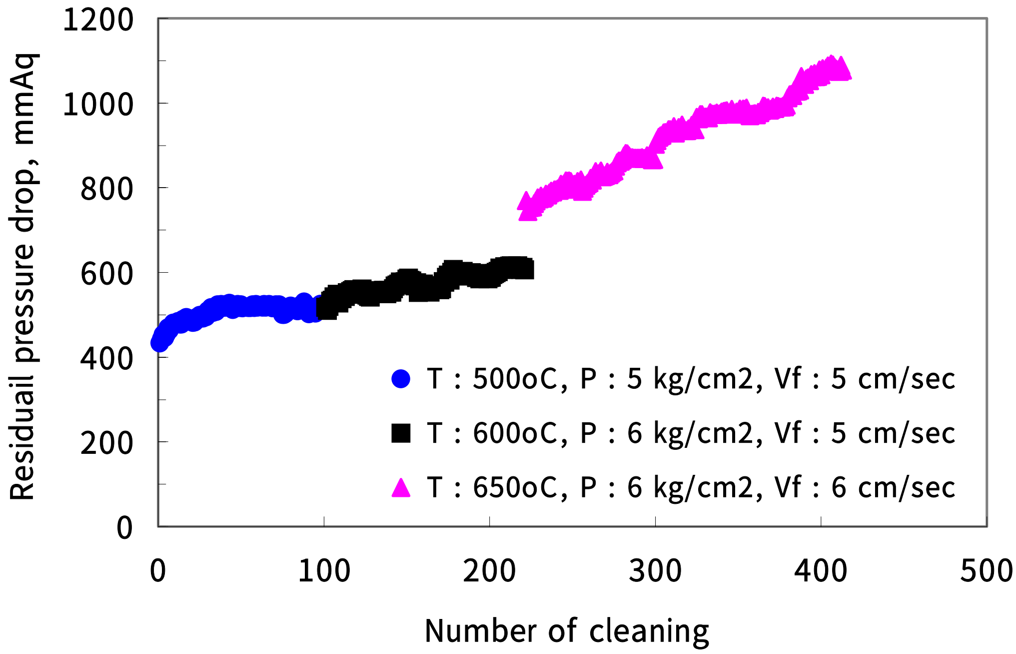

Figure 4. Residual pressure drop along the number of cleaning.