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Performance of a Group Candle Filter in a Hot Bench Unit

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Abstract — The mounting technology of ceramic candle elements utilizing disk spring was tested in a hot bench unit. Seven SiC candle elements were fixed in three groups by 2, 2, and 3 elements per group. And its performance was investigated in a hot gas stream using oil burned- exhaust gas. The experimental results showed that this mounting method gave a good performance enough to be useful for the particulate removal in the integrated gasification combined cycle (IGCC). Some operational characteristics of the group filter were observed.

1. Introduction

Ceramic candle filter has been known as the most promising system for particulates removal in the advanced coal utilizing systems like IGCC[1]. Particulate removal at high temperature in these systems has special advantages to protect gas turbine, to increase the thermal efficiency, and to meet air pollution regulation standards. The higher the operation temperature of the particulate collector is, the higher the thermal efficiency is. However, the thermal efficiency of the IGCC plant is not so much improved as the temperature increases when the operation temperature is above 450℃[2]. And the considerable difficulty has been experienced with hot gas filters at high temperature above 800℃. Therefore, it is practical that the filtration for IGCC will be operated at 450~650℃. This temperature range is also reasonable for the operation of the regenerative H_2S absorbents, such as iron oxides and zinc titanates, which are utilized in a consecutive process for hot gas clean up in IGCC. The operation pressure ranges from 25 to 35 bar, which is the same as that of gasification step. The acceptable limit of particulate concentration entering an advanced gas turbine is significantly low. For example, particulates larger than 10 μm should be removed for a Siemens gas turbine[3]. So it is generally recommended that the slip particle size and total concentration of particles should be less than 5 μm and 10 ppm, respectively, for advanced power systems[1], which means the total filtration efficiency should be higher than 99.9%. Ceramic candle filter is one of the most reliable systems to confirm the filtration efficiency.

Ceramic candle elements are fixed in the tube sheet through holes and arranged vertically in the filter shell. In general, the filter elements are fixed on the tube sheet through the adequate holes. The hole has an extra room to compensate the expansion of materials at high temperature. In order to seal, ceramic gasket is placed between the metal and ceramic surface. Ceramic gasket acts as the part of cushion and/or sealant in this case. The art of skill for the mount of the filter element depends on how to compress the gasket in order, not only to seal the system and to prevent the filter element being lifted by the differential pressure drop across the tube sheet, but also to supply the free space for the metal expansion. Counter-down weight has been widely used in the high temperature application like PFBC[4]. Welding method of the light hold-down disk was reported by Ciliberti *et al.*[5] in order to reduce the weight load. System using a spring is also one of the beneficial methods to reduce the weight load. However, there remains a seriouse problem while using the metallic spring because of the strength reduction due to the corrosion of metals at high temperature. The utilization of ceramic spiral spring was proposed in a report funded by US. DOE[6].

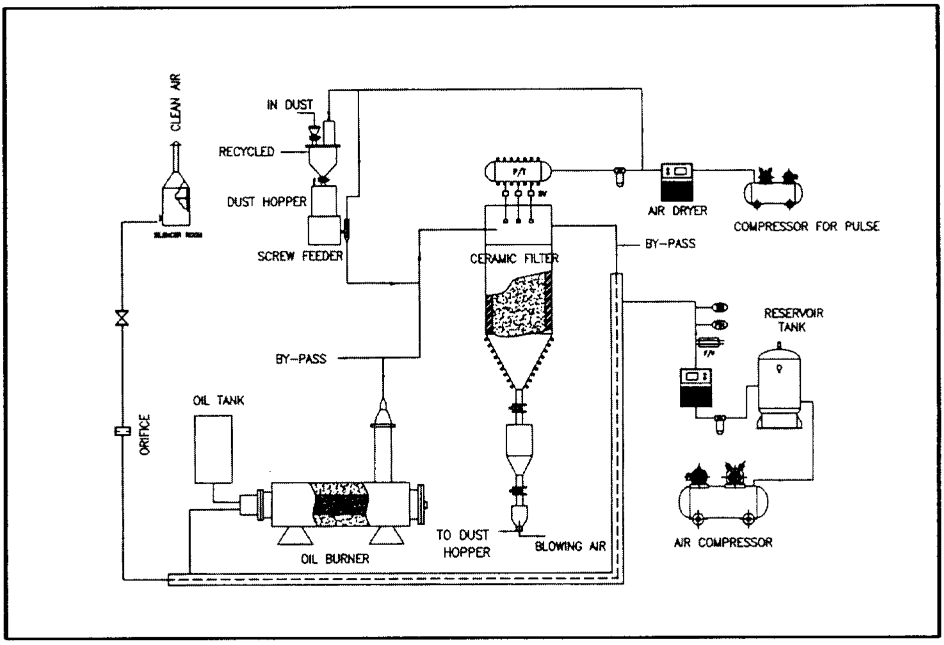

Fig. 1. Schematic diagram of an experimental unit for ceramic candle filter.

All of these methods have been demonstrated in several tests and field units in order to improve the system reliability. In this study, we utilized the disk metallic spring in order to reinforce the metallic hollow spring and to reduce the load of counter down weight. And the performance of the ceramic filter unit using the method was investigated.

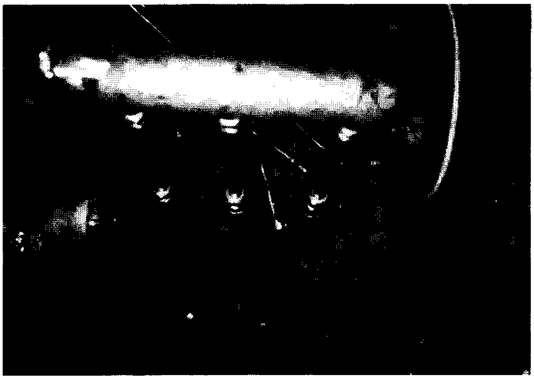

Fig. 2. Photograph showing the arrangement of seven filter elements.

2. Experimental

A schematic diagram of the experimental unit was shown at Fig. 1. The system consists of a ceramic filter unit, an oil burner, a dust feeder, and a pulse cleaning unit. The inner diameter and height of filter chamber are 500 and 2800 mm, respectively. Oil burned- exhaust gas was used as the hot gas stream into which fly ash from a conventional coal power plant was fed by a screw feeder. Seven candle elements with 1 m length were arrayed in three groups by 2, 2, and 3 elements per group like Fig. 2. Total filtration area is 1.26 m^2. Candle holder, has adequate hole to hold candle head, with the free room for thermal expansion of metallic tube sheet. Sealing was achieved by placing ceramic gasket on the surface of candle head and neck. Candle element was compressed tightly by screwing the diffuser using disk springs. Several numbers of disk spring were placed between the diffuser and the nut in order to absorb the thermal expansion.

SiC candle filter elements were supplied by Schumacher Co. Its trade name is Dia-schumalith TF-20 based on ceramically bonded silicon carbide and their properties were reported by Durst *et al.*7).

It has a thin outer ceramic membrane composed of a mixture of SiC grain and alumina oxide fibres, which is about 100~200 μm thickness and has a mean pore size of about 10 μm. The inner and outer diameter of the candle element are 40 and 60 mm, respectively.

The filtration performance was monitored by measuring the pressure drop across the filter elements, which denotes the total pressure difference between the upper and lower parts of the tube sheet.

3. Results and Discussion

The operation conditions of the system were summarized in Table 1. The temperature in the filter unit was controlled by the adjustment of oil feeding and air flow rate. The range of operating temperature was between 200 and 450°C. The inner diameter of nozzle was 6 mm. The total filtration efficiency (ET), which was defined as equation 1, was more than 99.9% at the given operation conditions. The concentrations were calculated by measuring the total mass and the total flow rate passing through the gasket impactor [ANDERSEN MARK III particle sizing stack sampler]. The inlet concentration of particulates ranged from 20 to 40 g/nm^3.

$$E_T = \frac{\text{Inlet concentration} - \text{Outlet concentration}}{\text{Inlet concentration}} \times 100\,(\%) \qquad (1)$$

Most of large particles above 5 μm was removed according to the measurement of particulate distribution of outlet gas stream with an aerodynamic particulate analyzer (API AEROSIZER) during the normal test duration. This result shows that the ceramic filter system designed in this study meets the specification of the filtration efficiency for advanced coal power plants such as IGCC.

Table 1. Operation conditions and performance of a hot bench ceramic filter unit.

Operating temperature	200~450°C	Pulse cycle duration	15~45 min
Operating pressure	2 bara	Face velocity	1~5 cm/sec
Nozzle inner diameter	6 mm	Particle slip size	less than 5 μm
Pulse pressure	5~9 bara	Total filtration efficiency	more than 99.9%
Particulate loading	20~40 g/nm^3	Duration (continuous)	120 hr
Pulse duration	0.2~1.2 sec	Duration (accumulated)	2,500 hr

In normal operation (filtration), gas passing through the filter element meets four distinctive resistance layers; porous support, membrane, residual dust cake, and temporary dust cake. So pressure drops developing during the filtration are divided into three main cases, as shown at Fig. 3, through filter element (ΔP_F), residual cake (ΔP_R), and temporary dust cake (ΔP_C). The sum of pressure drops through filter element and residual cake denotes the base line pressure drop (ΔP_B). The trend of ΔP_B variation is very useful to monitor the performance of the filtration at a given condition. The higher the value of ΔP_B, the more the pulse energy is consumed to clean the filter element. The limit of ΔP_B depends on the system design and operating conditions. It

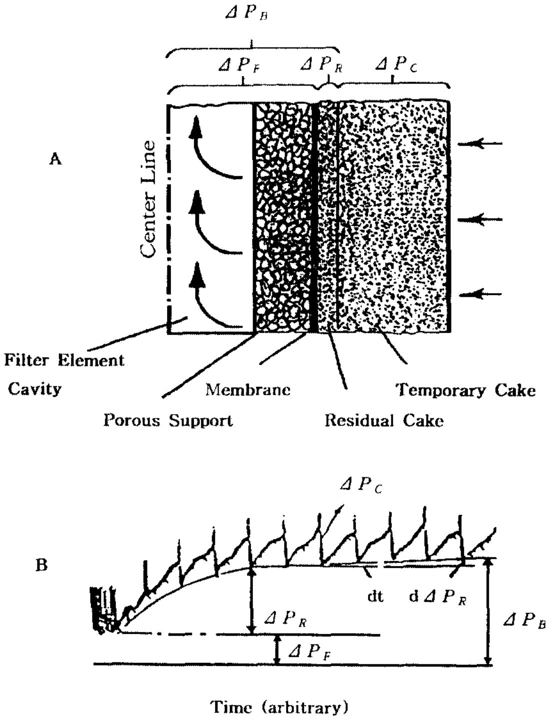

Fig. 3. The cross section of filter element (a) and the typical pressure drop during the operation of candle filter.

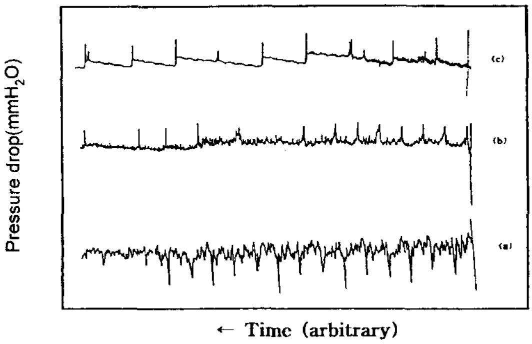

Fig. 4. The patterns of the pressure drop development through ceramic filter during conditioning; initial (a), after 1 hr (b), and after 3 hr (c).

was, for example, designed as 2,000 mm H_2O in Grimethorpe PFBC[4].

Figure 4 shows the typical patterns of the base line pressure drop during the first stage of operation using the fresh filter element. The base line pressure drop was very unstable at the initial stage as shown at Fig. 4(a). However, it was stabilized gradually owing to the formation of the residual layer, which showed the stable pattern after more than 3 hours as shown in Fig. 4(b) and Fig. 4(c). The temporary dust cake is removed during the pulse cleaning.

Pressure drop (ΔP) through the rigid ceramic filter element is generally expressed by Darcy's law as equation 2. Where k is permeability, η is dynamic viscosity, and V is face velocity which denotes the actual total flow rate divided by the actual filtration area. The permeability decreases with time as the dust cake becomes thick and as the particulates penetrated plug the hole of filter element. Figure 5 shows a typical pattern of the variation of the permeability during the initial time. The initial permeability is about 2.0×10^{-9} m which is the similar value reported by others[8] using the same SiC filter. The relative permeability expressed by equation 3[9] is convenient to find the filteration performance. Where subscript zero means the initial values. The relative permeability of fresh filter element decreased rapidly during the initial time and approached to a stable point finally at a suitable operation conditions as shown in Fig. 6. Schiffer *et al.*[8] reported that the relative permeability dropped to 40% during the first 500 hours of operation.

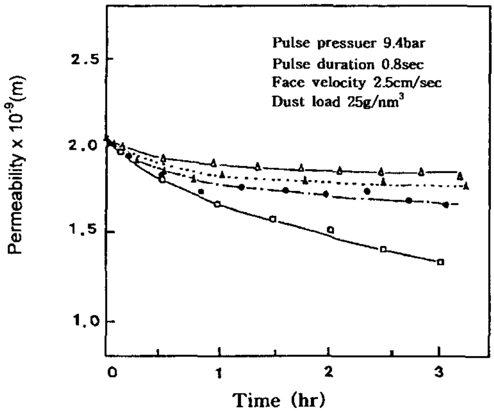

Fig. 5. The permeability change with the variation of pulse cycle duration; 5 min (△), 10 min (▲), 15 min (●), and 20 min (□) at 450°C.

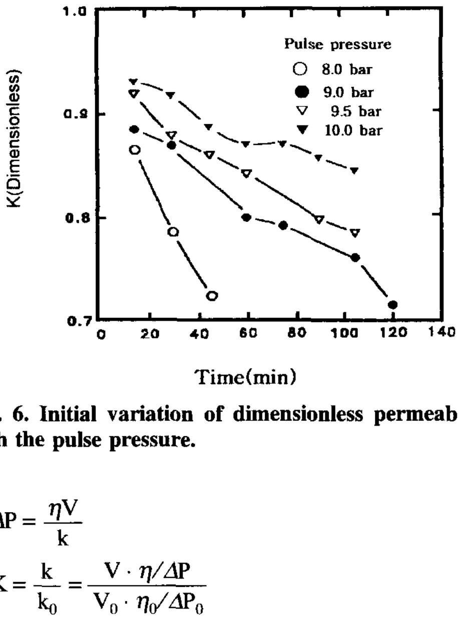

Fig. 6. Initial variation of dimensionless permeability with the pulse pressure.

$$\Delta P = \frac{\eta V}{k} \tag{2}$$

$$K = \frac{k}{k_0} = \frac{V \cdot \eta/\Delta P}{V_0 \cdot \eta_0/\Delta P_0} \tag{3}$$

Pressure drop through the bare filter element had a linear dependency on the increase of the face velocity as shown in Fig. 7. However, pressure drop increased according to a power law with larger order than the one when the particulates were applied. The reason of the increase of the pressure drop when the particulates were applied is due to the packing effect of the dust cake at high face velocity. Figure 8 shows the packing effect of dust cake at large dust loading and at high face velocity. It shows the hysteresis effect, on the pressure drop

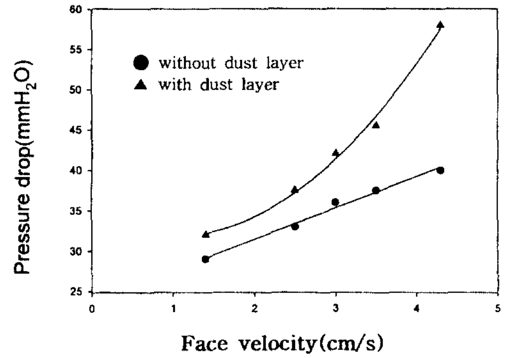

Fig. 7. Effect of the face velocity on the pressure drop.

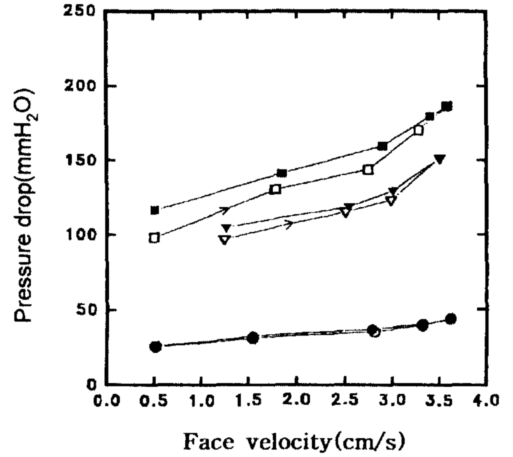

Fig. 8. Pressure drop through the filter element with the variations of face velocity with the path increasing (open) and decreasing (full) at 350°C.

through the filter element pre-covered with dust cake, in the different paths of increasing and decreasing the face velocity. And the thicker the dust layer was, the more severe hysteresis was observed.

The pressure drop rate through dust cake (r_C) depends on the face velocity and dust concentration. Figure 9 shows r_C is fitted with a curve of second order with the face velocity. And it had a linear dependence with the particulate load as shown in Fig. 10. These results meet well with the equation 4 reported by the Lipert's[10]. Where, μ is gas viscosity, ρ_g is gas density, ρ_c is dust cake density, X is solid mass loading, k_c is dust cake permeability per meter.

$$r_c = d(\Delta P_c)/dt = \frac{(\mu \cdot \rho_g \cdot X \cdot v^2)}{(k_c \cdot \rho_c)} \tag{4}$$

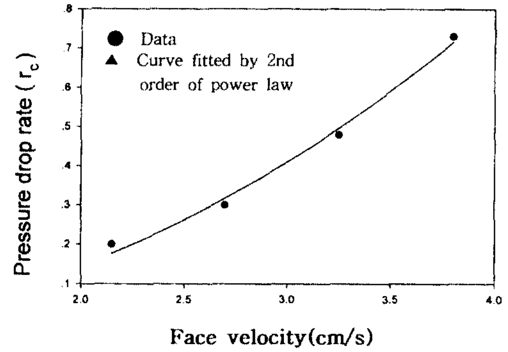

Fig. 9. The effect of face velocity on the pressure drop rate through the dust cake.

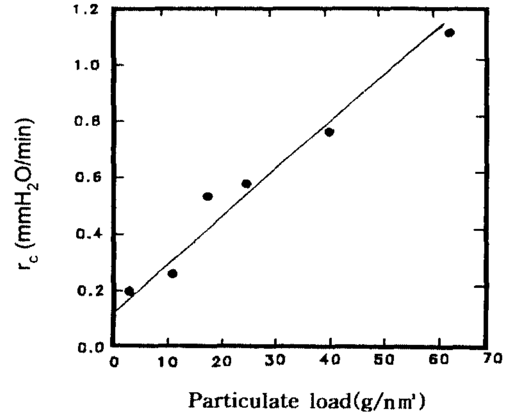

Fig. 10. The effects of particulate load on the pressure drop rate through the dust cake: T 350°C, V 2.5 cm/sec, pulse duration 0.8 sec, pulse pressure 6.5 bar, and pulse cycle duration 15 min.

Pressure drop rate (r_d) expressed by equation 5 denotes the increasing tendency of residual pressure drop and is very useful to estimate the durability of the operation. Figure 11 shows that rd increases steeply when the face velocity is larger than 4 cm/sec. The reason why these values increase is that dust cake forms densely at high face velocity.

$$r_d = \frac{d\Delta P_B}{dt} \tag{5}$$

The commercially allowable limit of base line pressure drop for continuous operation is 2,000 mm H_2O[2]. And the initial pressure drop of fresh filter element is about 250 mm H_2O. Assuming the linear increase of r_d, The r_d should be 0.0036 mm H_2O/min when the total operation time is 8,000 hours for one

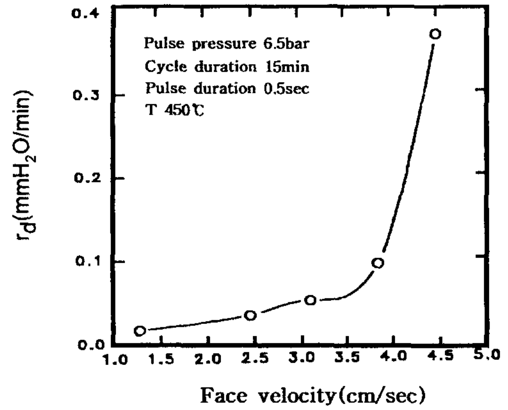

Fig. 11. The face velocity effects on the pressure drop rate.

year. So the pressure drop rate should be less than 0.003 in order to operate the system more than one year continuously. From the results of this study, the face velocity should be less than 2.5 cm/sec to meet this restriction.

4. Conclusions

The design technology of element mounting utilizing disk spring was tested in a bench scaled-ceramic filter unit using seven SiC candle elements. The filter element was mounted on the tube sheet by compressing with disc springs. The performance of the bench unit was investigated at high temperature above 400°C using oil burned- exhaust gas.

(1) The filtration efficiency was more than 99.9%. The particle size slipped from the filter was less than 5 μm. And the pressure drop showed the very normal trend of general ceramic filter. These results showed that the mounting technology using disc spring met well the specifications for advanced high efficiency filtration system.

(2) The virgin filter element showed an unstable pressure drop at the initial stage of operation but was stabilized after the formation of residual dust layer. And the permeability of ceramic candle filter decreased rapidly at the initial operation stage.

(3) The pressure drop rate through dust cake depended on the second order with the face velocity and linearly on the dust concentration. These results were well expressed with the Lipert's equation.

(4) Face velocity was an important factor which governed the formation property of the dust cake. And it was recommended the ceramic candle filter should be operated at low face velocity less than 2.5 cm/sec.

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References

1. Choi, J.H., Ji, P.S. and Chung, J.D.: "The Technical Evaluation of Current HTHP Gas Particulate Collectors for IGCC", Proceedings of The 3rd International Symposium on COAL COMBUSTION - Science and Technology, September 18-21, Beijing, China, 514-521 (1995).
2. Bakker, W.T.: "Effect of Gacifier Environment on Materials Performance in Syngas Coolers", 12th EPRI Conference on Gasification Power Plants, October 27-29, Hyatt Regency, SF, CA, USA, (1993) P7-1.
3. Mitchell, S.C.: "Hot gas particulate filtration", IEA Coal Research, London, UK, (1997).
4. Grimethorpe PFBC Establishment: "Grimethorpe High Temperature High Pressure Gas Filter Experiment Program", EPRI TR-100499, Vol. 2, 3-7 (1992).
5. Ciliberti, D.F., Boro, M. and Lippert, T.E.: "Filter Unit for Use at High Temperatures", U S Patent 4, 735,638, April 5, (1988).
6. Mark, W.J. and Stephon, A.G.: "Filter Assembly having a Filter Element and a sealing Device", U S Patent 5,401,406, Mar. 28, (1995).
7. Durst, M., Muller, M. and Vollmer, H.: "High Performance Dust Removal from Process- and Flue-Gases, Between Ambient Temperature and 1000°C, by Means of Asymmetric Porous ceramics", Stoubreinhaltung der Luft, 48, 197 (1988).
8. Schiffer, H.-P., Laux, S. and Renz, U.: "High-Temperature Gas Fiteration", Vol. 2, EPRI GS-6489, Final Report, (1992).
9. Clift, R., Seville, J.P.K. and Kuile, J.W.W.: "Rigid Ceramic Media for Filtering Hot Gases", Filtration & Separation, July/August, 265 (1989).

10. Lippert, T.E., Bachovchin, D.M., Smeltzer, E.E., Alvin, M.A., Mayer, T.H. and Hughes, L.A.: "Subpilot Scale Gasifier Evaluation of Cross Flow Filters", Proc. of 11th Annual Gasification and Gas Stream Cleanup Systems Contractors Review Meeting, Morgantown, 396-405 (1991).