Study of the Use of Bag Filters in Hot Gas Filtration Applications, Pilot Plant Experiences

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Abstract: A complete experimental campaign has been carried out in a hot gas filtration test facility so as to test different types of bag filters. The facility is designed to operate under a wide range of conditions, thus providing an excellent tool for the investigation of hot gas filtration applications for the conventional and advanced electrical power generation industry such as IGCC, PFBC or fuel cell technologies.

Relevant parameters for the characterization and optimization of the performance of the filters have been studied for a variety of operation conditions such as filtration velocity, particle concentration, pressure and temperature among others. Pressure drop across the filter, cleaning pulse interval, baseline pressure drop, filtration efficiency and durability of the filter have been investigated for each type considered and dependences on parameters have been established. On top of that, optimal operating conditions and cleaning strategies were determined.

The tests results show that bag filters are a suitable alternative for the hot gas particle removal due to the better performance and the high efficiency observed, which makes them suitable for industrial applications operating under high temperature and high pressure conditions considered within the study (200 ℃-370 ℃ and up to 7.5 barg).

Additionally, a technology based on combined dry removal of particles and SO_2 in a single step by using a high temperature filter unit and solid sorbent injection for large coal combustion power plants is proposed to be studied in this paper.

Keywords: Filtration, bag filter, high temperature, SO_2 sorption

1 INTRODUCTION

Hot gas cleaning systems are crucial for the establishment of coal based advanced power generation and hydrogen production systems. Ceramic candles seem to be the most promising hot gas filtration technology for removing solid contaminants. However, successful long term operation with candles is still limited mainly by design and/or materials [1, 2]. The unreliability of the ceramic filter elements in demonstration trials and the high capital cost of these systems have hindered their applications and are factors restricting the uptake of gasification power plants in general [3]. Therefore the identification of more suitable ceramic candle technology or alternative hot gas filtration technologies is required.

The operating temperature 200 ℃-370 ℃ (392 ℉-698 ℉) allows the option of bag filters as an alternative to be considered. In this sense, this paper summarizes the results from a complete experimental campaign carried out for the characterization and optimization of the performance of three types of bag filters under high temperature high pressure conditions. The test facility has been designed and operated at the ETS Ingenieros-University of Seville (Spain). Some fundamental limitations and practical issues regarding the operation of these filtration technologies have been identified.

The tests results show that high temperature fabric filter systems would be an alternative to particulate matter control on large coal-based power plants [4,5].

Moreover, the combined dry removal of particles and SO_2 in a single step must be taken into consideration. The application of a system based on the use of a high temperature filter and solid sorbent injection in pulverized coal combustion power plants downstream the economizer would involve several advantages, especially when a post combustion NO_x control device is necessary. In this sense, the study of that combined depuration process by using a high temperature fabric filter unit is proposed in this paper. This system, simpler and cheaper than a wet flue gas desulfuration and with several operation advantages [6], appears as an attractive engineering solution for coal combustion power plant units.

2 EXPERIMENTAL

2.1 Test Facility

A schematic diagram of the hot gas filtration test facility is illustrated in Fig. 1.

Main characteristics of the test facility are summarized in Table 1.

Table 1 Main characteristics of the test facility

Operating conditions	
Operation gas	Air/Exhaust gases
Particulate matter	Fly ash
Temperature (℃)	235-600
Pressure max (barg)	7.5
Gas flow max (Nm^3/h)	850
Filtration vessel dimensions	
Length (mm)	3,500
Diameter (mm)	450
Mass loading (kg/h)	1-22
Cleaning conditions	
Cleaning gas	Nitrogen/Air
Temperature max (℃)	600

Cleaning pulse max (barg)	20	Cleaning mode	Compartment /Not compartment

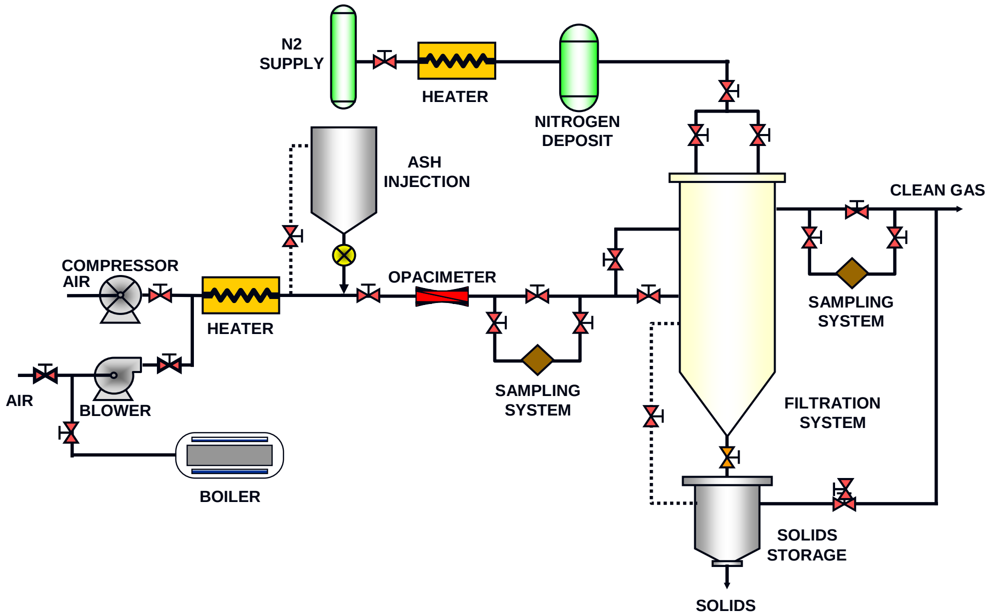

Fig. 1 Basic diagram of the test facility

The filtration vessel is divided into two sections: upper (or clean section) and lower (or dirty section) by the plate which supports the filters. The upper part of the vessel is also divided into two compartments or sections.

The pulse cleaning system consists of a compressed nitrogen reservoir (up to 20 barg), fast-action valves leading to the blow tube which injects the gas either in the open end of the filter. The temperature of the cleaning gas is the same as the operation temperature.

A particle sampling system has been specifically developed for this work with the aim of determining the particles concentration prior and after the filtration vessel.

More details of the facility are given in previous papers [4, 5, 7, 8].

2.2 Filters

As above mentioned, three types of bag filters have been considered within this study. The bag filters selected were Teflon PTFE, Polyimide P84 and woven glass textile 3 M FB700. Main characteristics of the filters are shown in Table 2.

2.3 Experimental Filtration Test Planning and Methodology

The test planning included every experimental parameter foreseeably having influence on the process. The parameters selected for the test definition are the following: filtration velocity, particle loading, pressure in the filtration vessel, temperature in the filtration vessel, maximum pressure drop across the filter, gas cleaning pressure, duration of the cleaning pulse and cleaning mode. The effect of these parameters can be described by means of a series of critical variables, so-called fundamental variables: pressure drop across the filter, cleaning pulse interval, defined as the period time between consecutive cleaning operations, baseline pressure drop, which is the pressure drop immediately after cleaning, filtration efficiency, durability or deterioration of the filters [5].

Table 2 Main characteristics of the filters

Composition	Teflon (PTFE)	P 84 (Polyimide)
Diameter	120 mm	120 mm
Length	1500 mm	1500 mm
Weight	700 g/m^2	550 g/m^2
Thickness	1.4 mm	2.8 mm
Void volume	78 %	86 %
Elongation at break	15 % Lengthwise 30 % Crosswise	20 % Lengthwise 30 % Crosswise
Operating temperature	260 ℃	260 ℃
3 M FB700		
Composition	Woven glass	
Diameter	120 mm	
Length	1800 mm	
Superficial density	746 g/m^2	
Maximum stress	35.7 kg/cm^2	
Maximum operation temperature		
Continuous	370 ℃	
Peak	427 ℃ , 15 min/day maximum	

3 RESULTS AND DISCUSSION

Firstly, characterization tests were done to define the test matrix and the base case. After determining test matrix, shown in Table 3, operational tests were performed.

Table 3 Test Matrix

Experimental parameter	Levels		
Filtering element	P84	PTFE	3M FB700
Filtration velocity (cm/s)	1.1/1.6/2.1		0.9/1.1/1.3
Particle loading (g/Nm^3)	7/14/21		
Pressure in the vessel (barg)	4.5/7.0		
Temperature (℃)	235		235/370
ΔP_{max} (mmwc)	170/200		120/150
Gas cleaning pressure (barg)	12.0/13.0/13.5/14.0/14.5/15.0/16.0/17.0/18.0/19.0		
Duration of the pulse (ms)	400/500/700/800/900/1000		

Table 4 shows the average particle removal efficiency determined under stable operating conditions by means of isokinetic samplings performed during the experimentation at the outlet and the inlet of the filtration vessel.

Table 4 Average efficiency determined during stable conditions for the different filters

Filter	Efficiency average
P84	99.80
PTFE	99.98
3M FB700	99.50

During the first tests using P84 bag filters, without any apparent mal-operation, the gas particle concentration at the outlet of the filtration vessel was increasing up to 214 mg/Nm^3, equivalent to an efficiency of 98.4%. By checking the filters, a diminution of the total length (around 11.5 cm) was observed, surely due to the effect of the temperature. In order to verify this effect, a new set of P84 bag filters was installed and the operation continued but at a lower operation temperature (200 ℃-220 ℃). After 4 weeks of operation, a reduction in the length of the filters was also detected although it was less noticeable (2 cm-3 cm). The outlet particle concentrations measured with the new bag filters were 16 mg/Nm^3-22 mg/Nm^3.

For PTFE bag filters, the efficiency was higher than 99.98%. The outlet particle concentration was less than 3 mg/Nm^3.

For 3 M FB700 filters, the average efficiency determined was 99.5%. The outlet particle concentrations measured was between 15 and 155 mg/Nm^3. Better results were achieved when operating at 370 ℃, with an average efficiency of 99.7%, which implies an outlet particle concentration around 5 mg/Nm^3. However, the filtration velocity was slightly inferior, about 1 cm/s. Thus, important potentiality for higher temperatures filtration applications (370℃ compared to 235 ℃) has been disclosed for this type of filters.

Effect of the Operational Parameters

Dependence of the fundamental variables on gas cleaning pressure, maximum pressure drop, duration of the pulses and filtration velocity has been determined. Examples of the measured pressure drop curves during de tests are shown hereby.

A low limit of ***cleaning pressure*** below which the operation was not feasible was determined, around twice the pressure into the vessel. As general result, the more effective values were 19 barg approximately; however the improvement of using higher pressures than 13.5-16 barg, operating at 7-7.5 barg, was not very significant when and therefore these values were selected in order to minimise the consumption of nitrogen. Fig. 2 shows that the operation under the specified conditions was not stable when using 13.5 barg nitrogen pulses but stable when 14.5 barg.

The frecuency of the cleaning pulses decreases with the high level of P_{max}, as observed in Fig. 3.

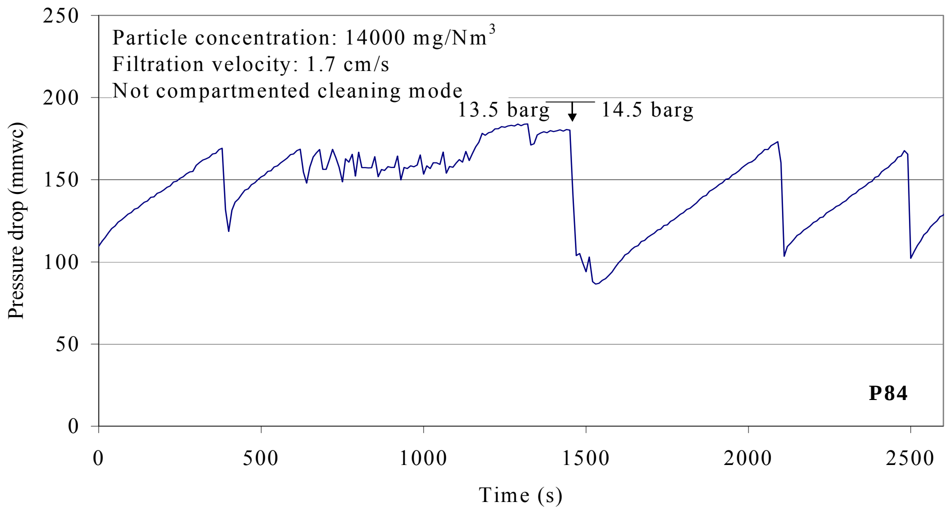

Fig. 2 Effect of cleaning pressure (operation pressure: 7 barg)

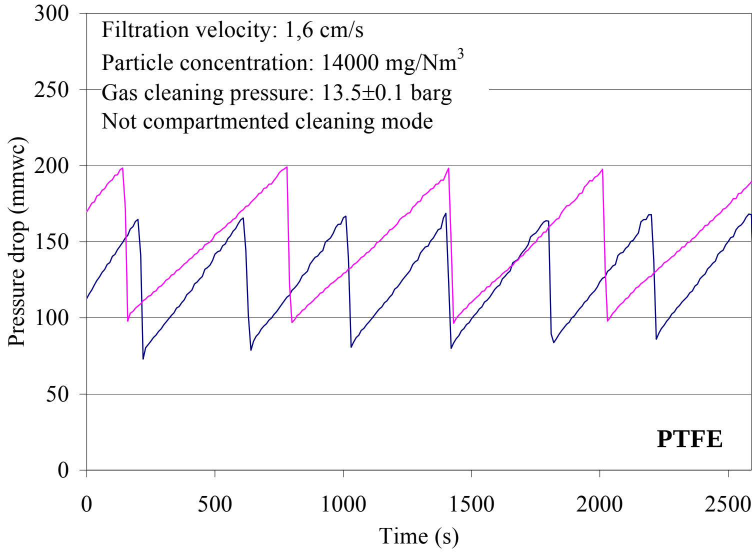

Fig. 3 Influence of the Pmax

It is observed that baseline pressure drop increases with the ***filtration velocity*** and cleaning pulses are to be more frequent, as expected, and this way determining a maximum value for the filtration velocity. Table 5 summarises the maximum filtration velocity values and the corresponding Δ*P* value compatible with a stable and feasible operation.

Table 5 Maximum values of filtration velocity and ΔP compatible with stable operation

Filter	Max filtration velocity (cm/s)	ΔP_{max} (mmwc)	Manufacturer ΔP_{max} (mmwc)
P-84	1.6	170	120
PTFE	2.0	170	120
3M FB700	1.1	120	120

The ***duration of the pulses*** seems not to have a very significant effect as long as they are short duration pulses.

4 COMBINED DRY REMOVAL OF PARTICLES AND SO_2

As above-mentioned, the application of a high temperature filtration technology combined with the use of solid sorbent injection in conventional coal combustion power plants would involve several advantages, especially when a postcombustion NO_x control device is required.

The most employed post-combustion NO_x control technology in large coal combustion power plants is the Selective Catalytic Reduction (SCR) [9] In a SCR system, the optimum temperature depends on both the type of catalyst utilized in the process and the flue gas composition. For the majority of commercial catalysts, the optimum temperatures for the SCR process range from 480 ℉ to 800 ℉ (250 ℃ to 427 ℃) [10].Therefore, most of the SCR systems are disposed downstream of the economizer.

Ammonia-sulphur salts, fly ash, and other particulate matter in the flue gas cause blinding, plugging or fouling of the catalyst. The particulate matter deposits on the surface and in the active pore sites of the catalyst. This results in a decrease of the number of sites available for NO_x reduction and an increase in flue gas pressure loss across the catalyst. Impingement of particulate matter and high interstitial gas velocities erode the catalyst material. Moreover, the ash typically contains arsenic, alkali metals, and other constituents that are detrimental to catalyst performance and life. For designs utilizing a honeycomb catalyst, the catalyst pitch is typically about 7 mm to 9 mm to allow easy passage of ash particles without deposition and for ease of cleaning with soot blowers (high-dust SCR)

A low-dust SCR system increases catalyst life by reducing concentrations of particles and catalyst poisons in the SCR reactor. In addition, low-dust SCR configurations do not need ash hoppers. The catalyst pitch can be reduced to approximately 4 to 7 mm, resulting in lower catalyst volume. Longer catalyst life, lower catalyst volume and the elimination of the ash hopper mean lower costs for low dust SCR compared to high-dust configurations. However, low-dust SCR systems need a high filtration temperature device and because of the higher temperature of the flue gas, the gas volume treated in the FF is larger. Consequently, the overall size of the filter unit is larger making it more costly [10].

On other hand, SCR catalysts promote the formation of SO_3, formed by the oxidation of SO_2 to SO_3 [10]. The increased SO_3 concentration also causes acceleration of corrosion of downstream equipments, increased possibility of ammonium bisulphate formation within air preheater elements and increased PM emission. Moreover, SO_2 emissions must be reduced under the legal limits. The system of wet desulfuration process (WFGD) is the most usual deSO$_x$ technology in large coal combustion power plants and it is disposed downstream the economizer [9]. WFGD offers SO_2 removal efficiencies around 95%. But design and operation are both complicated implying high cost and requiring considerable amount of water consumption and water re-treatment. In this sense, dry SO_2 removal process using different solid sorbents are being studied as a cheaper alternative. However, there are still some issues to make dry desulfuration of flue gas be applied commercially. The Multi-pollutant Emission Control Technology Options for Coal-fired Power Plant report, prepared by the Energy Technologies Enterprises Corporation for the U.E. Environ-mental Protection Agency (EPA) and published in 2005 incorporates SO_2 sorbents injection involving the injection of a calcium or sodium based sorbent into the flue gas duct, somewhere between the air preheater and the ESP or FF, typically in the range 120 ℃-175 ℃ (250 ℉-350 ℉). This technology would be in the pilot scale to pre-comercial demonstration state, with an estimated cost lower than a WFGD, but with SO_2 remove efficiencies between 40%-85% [6]. Laboratory scale studies using simulated gas, $NaHCO_3$ injection and ceramic candles show an improve-ment on the SO_2 remove efficiency when temperature is increased: over 80% at temperatures higher than 300℃ and up to 100% around 400 ℃ [11]. A reference value given by EPA for the temperature downstream the economizer in a pulverized coal power station is 690 ℉ (366 ℃) at 100% load. In the ENDESA pulverized coal power station in Spain, this temperature is typically in the range of 300 ℃-370 ℃. In this sense, the combined dry removal of particles and SO_2 in a single step by using a high temperature filter unit with 3M FB700 appears to be an attractive engineering solution for coal combustion power plants units.

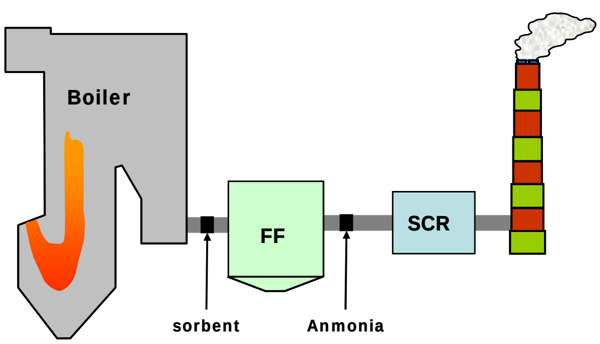

Fig. 6 Particulate matter, SO_2 and NO_x control with high temperature filtration

5 NEXT ACTIVITIES

A complete experimental campaign is to be carried out in the hot gas filtration test facility with the aim to compare 3M bag filter and ceramic candles using solid sorbent injection to remove SO_2 at 370 ℃ form exhaust gases in a diesel boiler system. SO_2 and sorbent injection devices are to be implemented in the test facility.

6 CONCLUSIONS

The characterization and optimization of the performance of three types of bag filters has been performed in a hot gas filtration facility. The tests results show that bag filters are a suitable alternative for industrial applications operating under high temperature and high pressure conditions.

Regarding the particle removal efficiency, the highest values, 99.98%, were found in PTFE at 235 ℃.

The comparatively high efficiency measure for the 3 M FB700 filters at 370 ℃, 99.70%, supports further research work with the aim to develop a new technology capable to improve the current systems of emissions control, particularly particles and SO_2, in large coal combustion power plants.

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