IMPACT OF CHAR AND ASH FINES ON POROUS CERAMIC FILTER LIFE

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ABSTRACT

Although frequently inert, char and ash fines can potentially have a deleterious impact on the life of porous ceramic filters that are currently being utilized in advanced coal-fired applications. This paper reviews several of the char and ash related issues that have been encountered in various Westinghouse Advanced Particulate Filtration systems which limited filter life.

INTRODUCTION

During the past 10-15 years, Westinghouse has been involved in the development of Advanced Particulate Filtration (APF) systems for removal of char and ash fines that are released during coal and biomass gasification or combustion. Initially individual porous ceramic filter elements were installed in slipstreams at the Kellogg Rust-Westinghouse (KRW) fluid-bed gasification test facility in Madison, Pennsylvania, and at the New York University combustion test facility in Westbury, New York. Recently these efforts have been expanded to the use of multiple cluster arrays containing 384 or 748 filter elements within a common pressure vessel at the American Electric Power (AEP) pressurized fluidized-bed combustion (PFBC) demonstration plant in Brilliant, Ohio, and at the Sierra Pacific integrated gasification and combined cycle (IGCC) test facility in Reno, Nevada.

Numerous phase changes and generally a loss of material strength were encountered during use of the monolithic first generation filters under PFBC conditions at AEP, as well as during operation in Ahlstrom/Foster Wheeler's pressurized circulating fluidized-bed combustion (PCFBC) test facility in Karhula, Finland.[1,2] When catastrophic failure of the first generation monolithic filter elements occurred, it generally resulted from thermal fatigue or shock of the oxide-based alumina/mullite matrices, or from creep crack growth of the nonoxide-based clay bonded silicon carbide filter materials. Advanced second generation, fracture toughened, fiber reinforced filter elements are currently being developed and installed in W-APF systems in an attempt to mitigate catastrophic failure of the porous ceramic matrix during process operation. The stability and/or changes within the second generation filters materials are being evaluated in on-going test programs at the Westinghouse Science and Technology Center in Pittsburgh, Pennsylvania.[3]

Although the composition and morphology of the first and second generation filter materials change during exposure to advanced coal-fired and biomass process environments, the porous ceramic filter elements generally remain intact, surviving exposure to the process temperature and gas chemistry. Unfortunately failure and performance limitations (i.e., reduced gas flow permeability; decreased particle removal efficiency; etc.) have been encountered due to ash related issues as (1) bridging; (2) filter bowing; (3) inner wall blinding; (4) inner bore plugging; (5) wedging of fines between the ceramic filter flange and metal holder mount; (6) auto-ignition; and (7) membrane debonding in alkali-laden systems. The following section provides an overview of Westinghouse's field experience where filter life and performance have been limited by the deposition and adherence of char and ash fines.

FIELD EXPERIENCE

American Electric Power — Pressurized Fluidized-Bed Combustion

During the early test campaigns at AEP, the Westinghouse APF system was challenged with inlet dust loadings of 600 ppmw, consisting primarily of fine ash particles with a mass mean particle size of 1-3 μm. As a result of the small particle size and the tendency for the particles to sinter, dust built-up between filter elements, and along the dust sheds and plenum support pipes, forming compact bridges. Ash bridging lead to bowing and distortion of the clay bonded silicon carbide candles at process operating temperatures of 620-790°C, as well as random catastrophic failure of filters during plant startup and shutdown. Post-test inspection of the filter arrays indicated the close proximity and/or contact of the bottom closed end caps of adjacent bowed candles, and the fresh fractured surfaces at the base of the filter flanges.

When failure occurred during the early test campaigns at AEP, fines were released into the clean gas plenum and exhaust gases. During pulse cleaning, fines were reentrained and back pulsed into the inner wall of the remaining intact filter elements. Due to the relatively extensive open porosity of the 15 mm clay bonded silicon carbide filter support wall, fines filled the porous wall to depths of ~1-3 mm from the inner surface, reducing gas flow permeability through the elements.

Alternately during the later test campaigns at AEP, when the primary cyclone was inactivated, the filter array was challenged with dust loadings of 18,000 ppmw, consisting primarily of ash particles with a mass mean size of 27 μm. Ash bridging was not encountered after 1110 hours of operation at temperatures of 760-845°C. A tenaciously bonded ash cake formation, however, resulted along the metal filter holder mounts along the top arrays. Enhanced sulfur sorption occurred along the fines that encapsulated the top filter holder mounts, leading to the formation of magnesium sulfate hydrate ($MgSO_4 \bullet 6H_2O$) and anhydrite ($CaSO_4$).[4] The high thermal expansion of the ash fines which wedged in between the filters and metal holder mounts potentially caused failure of several of the low load beating elements to occur during multiple plant startup and shutdown cycles.

Once random failure of the filters was encountered, ash was released into the effluent stream, which was then back pulsed into the inner bore of the remaining intact filter elements. Due to the high particulate loading during conduct of the final test campaign at AEP, compact plugs of ash accumulated within the inner bore of select filter elements. Again due to the high thermal expansion of the ash in comparison to the ceramic filter matrices, crack formations resulted generally near the end caps of the clay bonded silicon carbide, alumina/mullite, and fiber reinforced chemically vapor infiltrated (CVI) silicon carbide candles after numerous plant startup and shutdown cycles. Although failure of these elements did not occur during process operation, removal and elimination of the elements from continued testing was warranted.

Comment

Irrespective of the high load bearing capabilities of the first generation monolithic filters, or the low load bearing capabilities of the advanced second generation filament wound or fiber reinforced filter matrices, successful extended operating life and performance of porous ceramic filters in high temperature coal-fired process applications will require mitigation of ash bridging events. Process control will also require that sorption of gas phase sulfur species be accompanied by subsequent removal of the fines without deposition and retention of tenaciously bonded dust cake layers along metal support structures. The tenaciously bonded sulfur-enriched ash conceivably limited the life of the low load bearing advanced filter elements, and lead to a labor intensive effort for removal of the remaining intact monolithic alumina/mullite and clay bonded silicon carbide candles, and second generation CVI-SiC composite filter elements.

Ash filling, blinding of the inner wall, or plugging of the inner bore leads to reduced gas flow permeability through the porous ceramic filter matrices and possibly decreases the dust cake removal capabilities during pulse cleaning. In addition, development of crack formations and a substantially increased weight of the elements results, and the capability to regenerate or clean the filter elements off-line becomes virtually limited. Obviously successful extended operating life and performance of the hot gas filtration system will require that ash bridging and wedging along the exterior of the filter elements, and ash filling, blinding, and/or plugging along the inner wall and bore of the filter elements be eliminated.

Ahlstrom — Pressurized Circulating Fluidized-Bed Combustion

During operation of the W-APF at the Ahlstrom PCFBC test facility in Karhula, Finland, 128 alumina/mullite candle filters were initially installed and operated at temperatures of ~900°C.[2] Failure of several of the elements was considered to have occurred during the first test campaign as a result of ignition of carbon monoxide-rich process gas in the presence of oxygen when the main air compressor malfunctioned. Generally the ~900°C PCFBC operating temperatures were considered to lower the thermal fatigue characteristics of the alumina/mullite matrix, through the formation of microcracks along the inner bore of the candle, which ultimately reduced the strength of the conditioned filter elements.

After removal of the alumina/mullite candles and installation of the clay bonded silicon carbide filters testing continued at temperatures of ~830°C. Creep crack growth of the clay bonded silicon carbide filters resulted, ultimately leading to elongation of the filter body and random catastrophic failure. As a result, efforts fostered the development of advanced high temperature, creep resistance binder-containing, clay bonded silicon carbide candle filters.

Foster Wheeler — Carbonizer and Combustor Test Facilities

In 1992, Westinghouse installed and operated an APF system at the Foster Wheeler carbonizer test facility in Livingston, New Jersey. Twenty-two alumina/mullite candles formed the filter array. Initially one element failed, and char fines were back pulsed into the inner bore of the remaining filter elements. During startup in an oxidizing environment, combustion of the fines resulted, and catastrophic failure of several of the alumina/mullite filter elements occurred. Although alternate first or second generation filter elements had not been subjected to similar operating conditions, limited survival of these materials to withstand auto-ignition is expected.

In 1993 an alternate array of candles was installed in the W-APF system and operated under second generation PFBC conditions at the Foster Wheeler. During a ~210 hour test segment, the cyclone plugged and the filter vessel was filled with ash fines, causing failure of several of the filter elements. Post-test inspection of the array indicated that a tenaciously bonded sodium-potassium sulfate eutectic melt formed along the outer surface of the filter elements, which then served as the collection site for the adherence of $CaSO_4$, CaO and $CaCO_3$ fines.[5] The formation of the eutectic melt readily caused debonding of the membrane along the outer surface of the clay bonded silicon carbide filters. The alumina/mullite candles were virtually unaffected. Additional reactions of the binder phase in the clay bonded silicon carbide filter elements with gas phase alkali released in the Foster Wheeler second generation PFBC effluent stream were also observed.

The deleterious impact of auto-ignition of char fines, as well as the formation of the mixed alkali eutectic phase and bed carry-over require more stringent process control in order to achieve successful long-term operation of the ceramic filter elements in the advanced particulate removal systems.

Texaco — Entrained-Bed Gasification

Westinghouse utilized cross flow filters during the early test campaigns at the Texaco entrained-bed gasification test facility in Montebello, California. Failure was encountered when the stacked plate alumina/mullite cross flow filters delaminated, and when char fines became wedged between the cross flow flange and metal filter holder mounts. Wedging and failure along the flange had also been observed during long-term durability testing of the cross flow filters under simulated high temperature, high pressure, PFBC conditions at the Westinghouse test facility in Pittsburgh, Pennsylvania.

During the later test campaigns, clay bonded silicon carbide and alumina/mullite candle filters were retrofitted into the Westinghouse filter vessel at Texaco. After ~400 hours of operation, the candles were removed, and were observed to be coated with a tenaciously bonded dust cake layer. Removal of the FeO(OH), $FeAl_2O_4$-enriched cake from the outer surface of the filter elements was extremely difficult, which ultimately lead to the removal of the membrane of the clay bonded silicon carbide candle filters.[5]

Biomass Gasification

In 1994 and 1995 Westinghouse operated a twelve filter element array at the IGT biomass fluidized-bed gasification test facility in Chicago, Illinois. Post-test inspection of the clay bonded silicon carbide filter elements after ~21 and ~30 hours indicated that either an ~5.3 mm brown or ~1-2 mm black dust cake layer remained along the outer surface of the filter elements. The Fe_3O_4, Fe_2O_3, C, K, and SiO_2-enriched dust cake layer which was easily removed from the filters generally retained the contour of the candle body.[4] Debonding and/or removal of the outer membrane of the clay bonded silicon carbide candles was not observed after short-term operation in the 675-916°C biomass gasification environment.

FILTER ELEMENT LIFE AND REGENERABILITY

Porous ceramic filter elements can be utilized for extended service operation as demonstrated by Westinghouse during conduct of the five test campaigns at AEP where several surveillance clay bonded silicon carbide candles successfully survived 5855 hours of operation. At AEP Westinghouse also demonstrated the regenerability of the clay bonded silicon carbide candles by initially brushing the ash cake layer from the outer surface of the filter elements, followed by water washing and drying. Nearly complete gas flow permeability was recovered for the filter elements in this manner. If ash blinding occurred along the inner wall or fines formed a compact inner bore plug, complete regenerability of the elements was not possible.

FILTER ELEMENT CONSTRUCTION

During field operation, the texture or roughness of the outer surface, as well as changes in the wall thickness of the filter elements dramatically impact the adherence and/or removal of the dust cake layer. As the texture or roughness of the surface increases, residual ash cake thickness tends to increase, leading to a reduced gas permeability through the filter wall. An optimal construction of the filter element is a uniform wall thickness along the length of the body and closed end cap areas. In this manner uniform removal of the dust cake layer can be accomplished during pulse cleaning.

FUTURE EFFORTS

Westinghouse will continue to explore the impact of char and ash fines on the stability of the porous ceramic filters during future testing at the Sierra Pacific Pinon Pine gasification test facility in Reno, Nevada, and at the Southern Company Services integrated gasification and combined cycle (IGCC) test facility in Wilsonville, Alabama, and at the Pacific International Center for High Temperature Research (PICHTR) biomass gasification demonstration plant in Hawaii. Testing is currently on-going at the Foster Wheeler/Ahlstrom test facility in Karhula, Finland, where advanced first and second generation monolithic and fiber reinforced filter elements are being subjected to 900°C PCFBC test conditions. As a result of these efforts, the ultimate viability, performance and robustness of the first and second generation porous ceramic filter elements will be challenged under a relatively wide gamut of process operating conditions — all of which are required to define successful long-term operation of the advanced high temperature particulate filtration systems.

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