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**Article**

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## Research paper

## Particulate control devices in Kemper County IGCC Project

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## ABSTRACT

Southern Company has commissioned a  $2 \times 1$  Integrated Gasification Combined Cycle (IGCC) facility in Kemper County, Mississippi. The plant demonstrated the Transport Integrated Gasification (TRIG<sup>TM</sup>) technology developed by Southern Company, KBR, and the U.S. Department of Energy (DOE). With a capability of generating up to 524 MW net, the plant also captures CO<sub>2</sub> from syngas produced from locally mined Mississippi lignite. Particulate Control Devices (PCDs), designed by Pall Corporation, are a critical component of the TRIG<sup>TM</sup> gasification process. The PCDs use dry filtration technology to remove essentially all the fine particulates from the syngas before it is sent to downstream processes for further gas clean-up, CO<sub>2</sub> capture, and, finally for use in combustion turbines to generate power.

The Kemper PCDs are designed to accommodate different types of filter elements for future optimization. The initial installation features the 2.5-meter long iron aluminate (FEAL) filter elements based on the extensive testing experience gained at the Power Systems Development Facility (PSDF). The PCD back-pulse system is equipped with the Coupled Pressure Pulse (CPP<sup>TM</sup>) blowback technology developed jointly by Pall's Schumacher Division and Karlsruhe Institute of Technology for online filter element cleaning. It is the first CPP<sup>TM</sup> application of this scale used for high-pressure, high-temperature filtration in a gasification process. The Kemper facility has achieved integrated operation with production of electricity, CO<sub>2</sub>, and other by-products from syngas per design specifications. This paper describes the operations, performance, and technical issues of both the PCD and the fines cooling and handling system that were encountered during the installation, unit commissioning, and extended operation with lignite.

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## 1. Introduction

Combustion turbines fired with coal-derived syngas require reliable dust filtration to protect the turbines from degradation by erosion, corrosion, or deposition. Syngas exiting the gasifier containing entrained fine ash and unconverted char particles can be scrubbed in particulate control devices (PCD) with candle filters that are suitable for high pressure and high temperature operations. The durability and reliability of the filter material is critical to this filtration technology. These properties have been the subject of study for several years at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama (Various combustion and gasification, 0000). The studies at the PSDF led to a fundamental understanding of filtration mechanisms, evaluation of filtration materials and development of economical filtration techniques.

Filtration of entrained particles in syngas is a challenge due to the diverse nature and configuration of the IGCC projects. A

Shell gasifier produced the syngas at the IGCC plant at Buggenum and the filter unit downstream was equipped with ceramic filters and operated at temperatures up to 545 °F and pressures up to 375 psig. The dust loading was up to 4500 ppmw (Scheibner and Wolters, 2002). Steady gasification operations demonstrated the feasibility of achieving nearly two years of operation with one set of filter elements. The Pinon Pine IGCC project was equipped with a KRW gasifier. This project also used ceramic candles to remove entrained particles in the syngas (National Energy Technology Laboratory, 2002). The filter candles failed repeatedly due to endemic operational issues with the fines removal system and the project was eventually terminated.

The entrained flow gasifier at the Puertollano IGCC plant filtered the entrained fines in the syngas with more than 1000 ceramic candle filters (Navarrete et al., 2005). Despite several attempts and modifications, the filtration system suffered from blinding of internal candle surfaces, candle breakage and other issues, significantly affecting plant availability.

Ceramic candles have excellent corrosion resistance, but with mixed results due to the fragility and sealing mechanisms of

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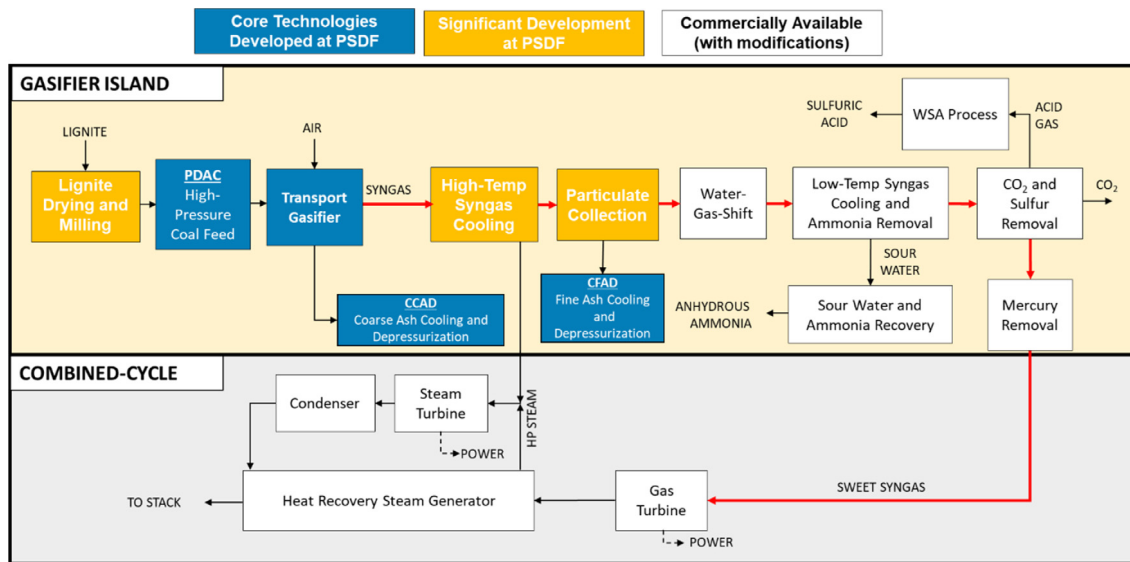


Fig. 1. Kemper county IGCC simplified block flow diagram.

the elements. Metallic filters offer much better mechanical properties (for example; less prone to shock, vibration and crack propagation) and a more secure sealing mechanism. Successful testing at the PSDF with syngas from a pilot Transport gasifier indicated good performance with iron aluminide candle filters in a gasification environment. These filter candles with effective peroxidation provide a thin, protective surface alumina that resists high-temperature corrosion in sulfur-bearing gasification environments. The testing at the commercial Wabash River gasification facility showed that iron aluminide elements offered superior particle collection efficiency (National Energy Technology Laboratory, 2008). The entrained fine ash and char particles in the syngas at Kemper were similar to that experienced at the PSDF. Iron aluminide filter candles were adopted for the high temperature, high pressure filtration needs at the large Kemper facility.

## 2. Kemper project overview

The Kemper County Project demonstrated a lignite-fueled 2-on-1 Integrated Gasification Combined-Cycle (IGCC) process located in Kemper County, Mississippi. The plant design incorporated the air-blown Transport Integrated Gasification (TRIG™) technology jointly developed by Southern Company, KBR, and the United States Department of Energy (DOE) at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama.

The design nameplate capacity of the plant is 830 MW with a peak net output capability of 582 MW. The peak capacity of 582 MW occurs using syngas in the combustion turbines coupled with natural gas firing in the duct burners. During syngas-only operations, the plant can achieve a net generating capacity of 524 MW. The facility produces marketable byproducts of ammonia, sulfuric acid and carbon dioxide. During normal lignite operations, the plant captures over 65% of the feed carbon with the resulting carbon dioxide used for enhanced oil recovery (EOR), making the facility's carbon emissions comparable to those of a natural gas-fired combined cycle power plant.

The plant construction and commissioning is complete, and it has operated with successful power generation for sustained periods firing syngas, while producing CO<sub>2</sub> and other byproducts per design specifications. The operation of the gasification portion of the plant was suspended in June 2017 primarily because of economic considerations due to the low-price forecast for natural

gas. The combined cycle portion of the plant continues operation with natural gas as sole fuel.

A simplified block flow diagram of the Kemper County IGCC plant is shown in Fig. 1. Refs. Nelson et al. (2017, 2018) provide detailed descriptions. The plant employs the TRIG™ gasification process, where Transport Gasifiers convert lignite into syngas for firing in combustion turbines. Gas processing equipment filters the syngas and removes contaminants prior to combustion in the combustion turbines. There are two combustion turbines, each with a dedicated gasification train supplying syngas to it. Each gasification train consists of a coal drying and milling system, a coal feed system, coarse and fine ash removal systems, and a syngas processing system. In addition, several auxiliary systems are common to both gasification trains, including the steam turbine.

Particulate-laden syngas leaves the gasifier at approximately 650 psia and is indirectly cooled from 1740 to 600 °F in syngas coolers, producing high-pressure superheated steam for use in the steam turbine. Subsequent dry gas filtration in the particulate control device (PCD), with barrier type filter elements, removes essentially all the particulates present in the cooled syngas stream, protecting downstream equipment. The filtered ash has 5–10 wt% carbon with a mass median diameter of 10–15 μm. A proprietary continuous fine ash depressurization (CFAD) unit moves ash from the filter vessel to the ash silo, while cooling and depressurizing it. From the silos, the removed fine ash is combined with coarse ash from the gasifier and sent to a temporary ash disposal location, before eventually being landfilled in the depleted lignite mine to reclaim the land.

The cooled and filtered particulate-free syngas is further processed in a series of gas clean-up systems to remove contaminants and produce marketable byproducts. The cleaned syngas is fed to combustion turbines for power generation.

After completing commissioning and extended operations for over 200 days with coal feed to gasifiers, the Kemper facility suspended operations involving the lignite gasification portion of the process in June of 2017. The combined cycle plant continued to operate using natural gas. Changes to the project economics were primarily driven by the dramatic decrease in the long-term price forecast for natural gas since the time that the project was approved in 2010. The updated long-term natural gas price forecast for 2017 and beyond indicated lower sustained natural gas commodity price forecasts by 25%–30% as compared to the 2016 forecast.

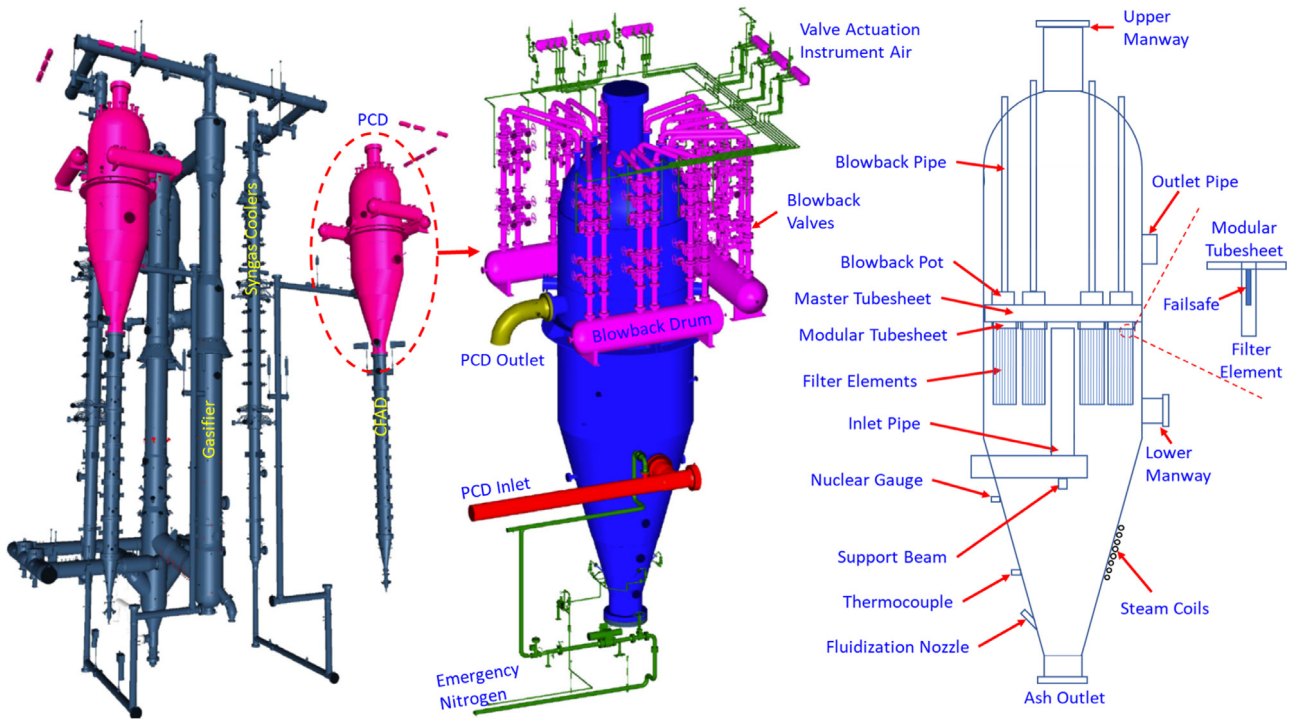


Fig. 2. A 3D presentation of PCD configuration.

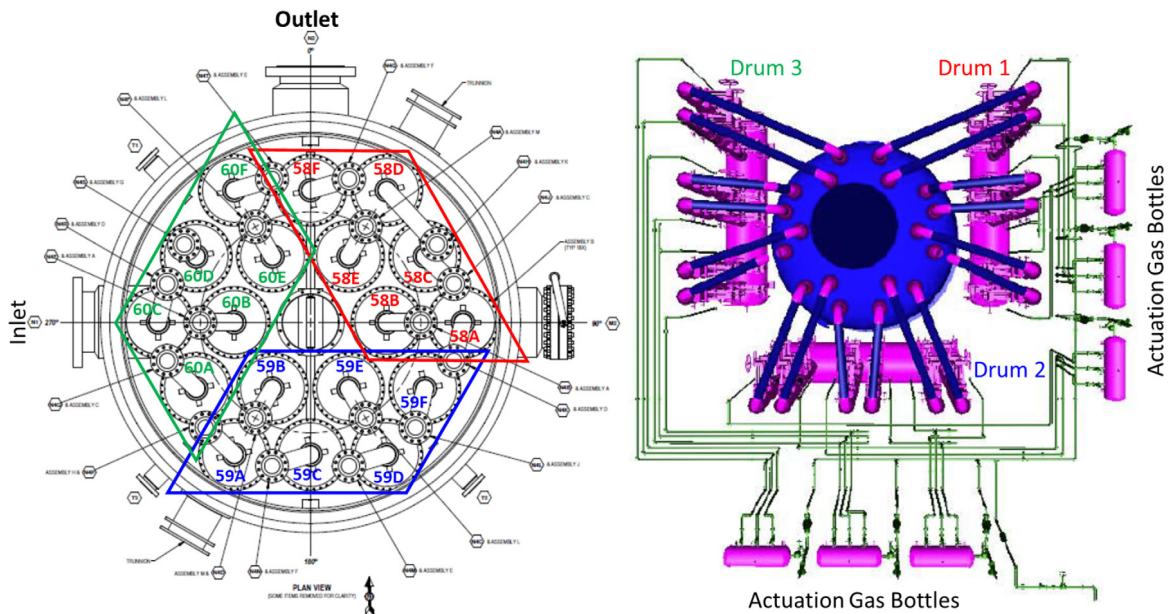


Fig. 3. Back-pulse pipe arrangement. 58A-F, 59A-F, and 60A-F are back-pulse valve (XV) numbers. Drums 1–3 are back-pulse gas accumulator numbers.

### 3. PCD and fine ash removal system designs at kemper

The particulate control devices are a key component in the TRIG™ process. There are four PCDs, two per gasifier train in a parallel configuration (see a 3D model in Fig. 2). The PCDs are designated as FL1106 and FL1206 in Train A, and FL2106 and FL2206 in Train B. The purpose of the PCD is to remove essentially all particulates from the syngas flowing from the syngas coolers. The PCD is a barrier filter system utilizing metallic filter elements. As syngas flows through the PCD, particulates collect on the outside of the filter elements and are periodically removed by injecting cleaned syngas from recycle syngas compressors to

the inside of the filter elements. The injected recycle syngas causes particulates to fall from the filter elements and into the lower cone of the PCD. From the PCD cone, the particulates travel through the PCD fines receiver, and into the CFAD system, while the particulate-free syngas flows from the PCD to syngas scrubber.

The PCD system consists of a master tubesheet that holds 18 clusters of filter elements in a modular arrangement. Each cluster, or module, contains 38 filter elements of up to 3 m in length. Inside each filter element, a built-in failsafe is installed at the mouth of the element. The PCDs are designed to accommodate different types of filter elements for future economics and optimization.

The initial installation features 2.5-meter long iron aluminide (FEAL) filter elements based on the extensive testing experience gained at the PSDF. The FEAL filter elements are constructed with sintered metal powder porous media in multiple sections connected by solid metal rings. They are welded to the tubesheet and interconnected by bar strips along the length as well as a support grid at the bottom ends.

All 38 filter elements in a cluster share the same chamber above the tubesheet to gather the filtered gas and receive the back-pulse gas. There are 18 back-pulse assemblies with one dedicated for each cluster (see Fig. 3). Outside of the PCD vessel, the 18 back-pulse assemblies are separated into three groups with six assemblies in each group. Each group has its own back-pulse gas accumulator and inlet gas filter. A fast-acting valve in the back-pulse line releases cleaning gas into the cluster when opened. The back-pulse event is controlled to strategically distribute the back-pulse gas to the individual clusters, one at a time. The back-pulse can operate in two modes: DP-mode, where a preset pressure drop across the tubesheet triggers the back-pulse; and continuous mode (with a fixed time between back-pulses).

The online cleaning of the filter elements is achieved by back-pulse with nitrogen during startup or recycled syngas during normal operation. It employs an innovative technology called Coupled Pressure Pulse (CPP™) jointly developed by Pall's Schumacher Division and Karlsruhe Institute of Technology (Mai et al., 2003). The CPP™ technology uses low pressure gas (less than 100 psi over system pressure) to clean the filter elements compared to traditional jet pulse cleaning via a venturi device that uses a high-pressure gas with pressures about two-times of the system operating pressure. As a result, there are no additional high-pressure compressors needed for the CPP™ technology, which has a cost benefit.

The CPP™ Technology directly couples the back-pulse pressure to deliver the cleaning gas to the filter elements by a device called hydraulic switch. The high cleaning intensity can be attained at a low back-pulse pressure. Although there have been applications of the CPP™ technology in biomass gasification and catalyst separation, the Kemper PCDs are by far the largest in scale and the first used for coal gasification.

The PCD is equipped with various instruments to monitor and control major operating parameters including the pressure drop across the master tubesheet, temperatures on the surfaces of selected filter elements, temperatures in the cone, the ash level above the cone, and back-pulse pressures in the accumulators. At the PCD inlet and outlet, gas compositions, temperatures and pressures are measured and monitored. Online particulate monitors from PCME Ltd. are also installed at the PCD outlet to detect any particulate leak through the PCD. Key parameters of these instruments are interlocked with operating control mechanism to maintain normal operation, detect system malfunction, and perform emergency procedures, if necessary.

Each PCD is equipped with thermocouples on filter element surfaces in strategically selected modules. These thermocouples monitor the surface temperatures and detect any thermal excursions in the filter cake, that contains certain amount of carbon from the gasification process. If there is oxygen breakthrough to the PCD at high operating temperature, combustion of the carbon in the cake may occur, resulting in a thermal excursion that may damage the filter elements. Control logic monitors the rate of change (ROC) in surface temperatures, triggering nitrogen injection to the PCD to dilute the oxygen concentration and cool the PCD internals. The emergency nitrogen flow is regulated by the PCD tubesheet pressure drop to protect the component from mechanical failure.

In the unlikely event that a filter element fails, the built-in failsafe effectively blocks the particulates, disabling the defective

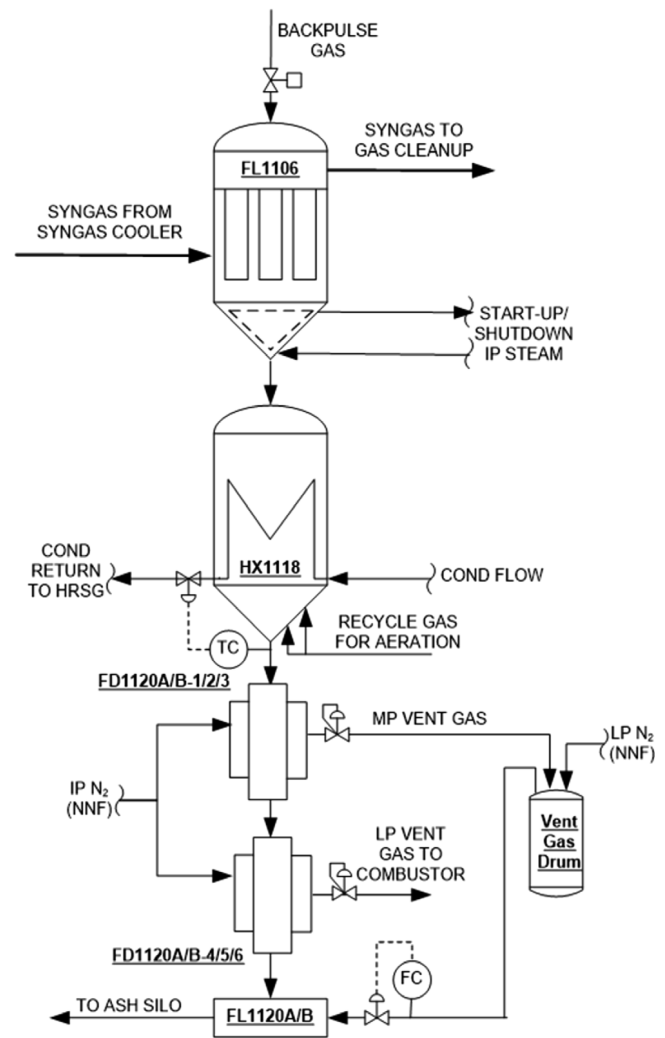


Fig. 4. Illustration of CFAD system for PCD fines cooling and depressurization.

filter element from service, while protecting downstream equipment from damage. The PCD is designed with excess capacity to allow for a design failure rate of the filter elements to seal off with the built-in failsafes. When the remaining filter elements can no longer perform the required filtration duty within the operating limits, the PCD must be brought offline to replace the damaged filter elements and restore the filtration capacity.

The PCD cone is equipped with steam coils on the outside of the shell to assist in pre-heating the PCD during startup to prevent condensate draining to the CFAD system. Skin thermocouples on the outside of the cone monitor the pre-heating process. After startup, the steam flow can be kept on, as needed, during normal operation to compensate for excessive heat loss or even to cool the PCD cone in the unlikely event that hot solids are carried over to the PCD from the gasifier.

The CFAD units at the Kemper facility cool and depressurize fine ash collected in the PCD. The innovative CFAD design was conceptualized and developed at the PSDF and was scaled up to commercial use for the first time at Kemper. Each PCD has a Fines Receiver directly attached to its cone to serve as a solids buffer between the PCD and CFAD depressurization system. The fines, dislodged from sintered metal filter elements in the PCD upon a back-pulse, fall through the PCD cone outlet and into the PCD Fines Receiver (HX1118 in Fig. 4), where five sets of cooling bundles cool the fines to below 350 °F as they flow through receiver/cooler vessel flowing downward in a moving bed.

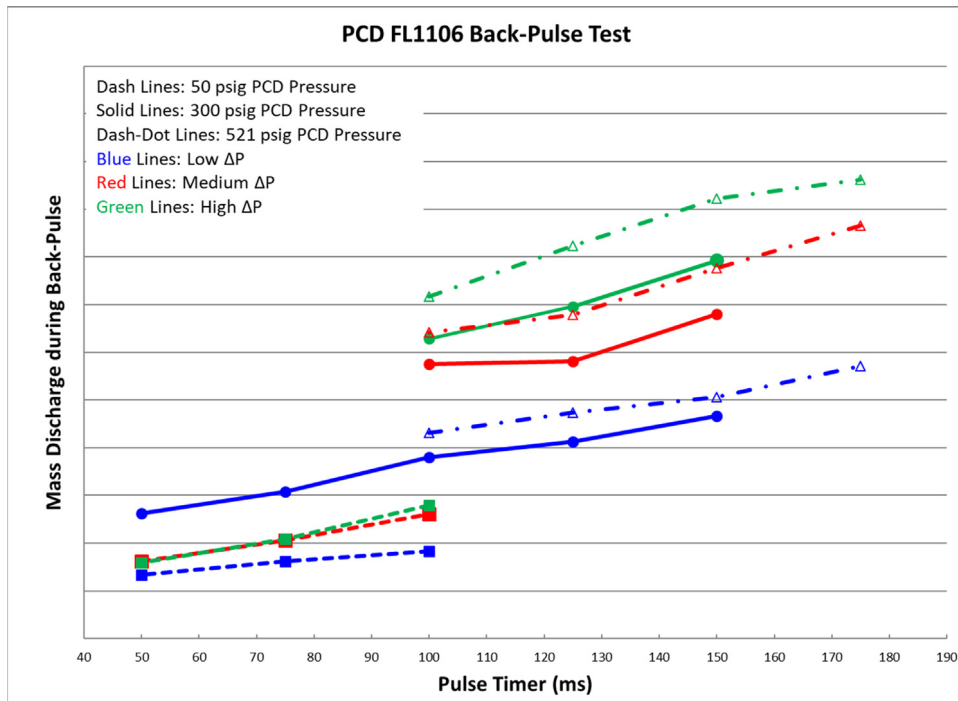


Fig. 5. PCD FL1106 back-pulse mass discharge.

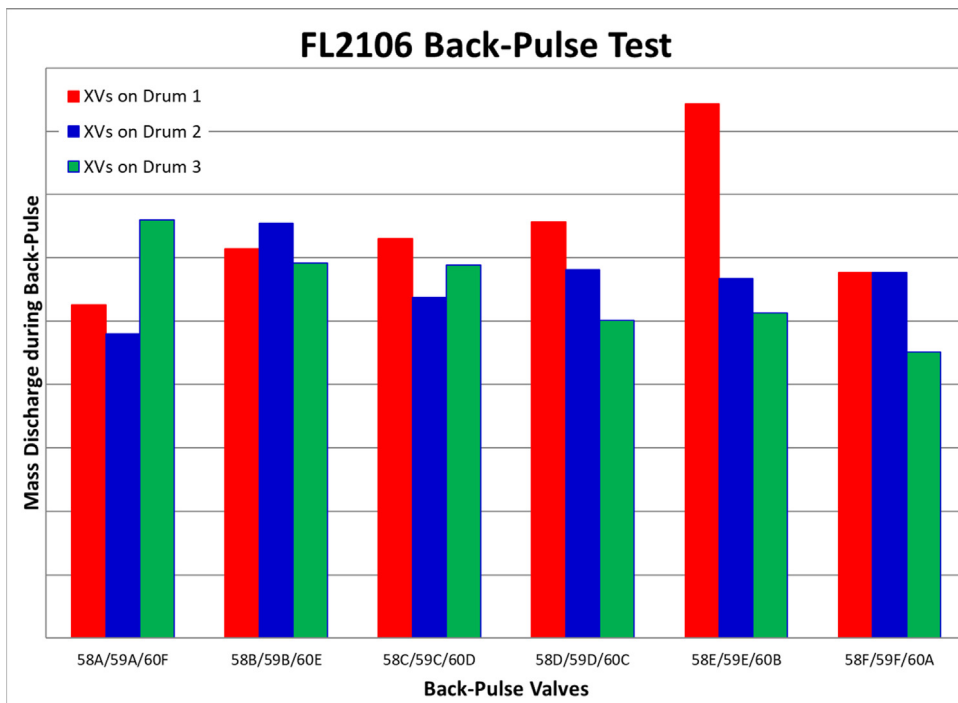


Fig. 6. PCD FL2106 back-pulse mass discharge.

Aeration in the cone section at the bottom of each receiver facilitates the flow of fines to two parallel sets of Pressure Let-Down Devices (PLDs). The PLDs depressurize the fines in stages that allow the gas entrained with the fines to escape as the fines flow through the PLDs. Each PLD train includes six stages of depressurization (depicted in Fig. 4 by FD1120A-1 through FD1120A-6) with vent gas pressure setpoints set at decreasing values for each stage.

The fines discharge rate is set to maintain a level in the receiver vessel above the cooling bundles, with the pressure

setpoint of the last PLD stage regulating the solids discharge rate. After solids exit the last PLD stage, they flow through the CFAD Clinker Catcher to separate and collect material larger than 1/2", which may include pieces of agglomerated ash, refractory, or other extraneous objects.

The gas vented from the first three PLD stages is collected in the PLD Vent gas drum. The Vent gas drum provides fluidization gas to the Clinker catchers and discharge lines, and provides conveying gas to transport fines to the ash silos. Vent gas from

the last three PLD stages is at a lower pressure and is normally vented to a combustor for disposal.

#### 4. Commissioning

The commissioning of the PCDs was conducted during gasifier tests that began in 2015. The PCD systems were tested to verify functionality, hardware operability, and control logic with focus on the back-pulse system, the key component of the PCDs. During the commissioning, the PCD back-pulse systems were lined up to the nitrogen header (recycle syngas is used with the back-pulse system during normal operation). The PCD cones were preheated by the steam heater. The back-pulse was started prior to adding start-up bed material (sand during commissioning) to the gasifier. The PCD FL1106 in Train A was chosen for the initial back-pulse test.

The back-pulse test was conducted at PCD outlet pressures of up to 500 psig. The minimum valve pulse timer, 50 ms, was selected as the initial setpoint. The differential pressure ( $\Delta P$ ) between the accumulator and the PCD outlet was varied within the allowable design  $\Delta P$  range. Because there was no coal feed, and thus no appreciable cake formation and varying tubesheet pressure drop, DP-mode was not tested. Only continuous mode was tested, the intended mode during coal-feed operation.

In general, the back-pulse gas discharge amount was significantly lower than expected per PSDF experience (only 1/3 of the gas discharge amount of the PSDF value at a high system pressure). The 50 ms pulse timer was short. Also, the back-pulse valve actuation was weak (slower or shorter) due to lower instrument air pressure and much longer installed piping in the field than the length specified by valve manufacturer. A modification was implemented later to install local instrument air bottles next to the back-pulse valves to improve valve actuation.

After the initial trial, the design back-pulse  $\Delta P$  was re-evaluated and updated to limit the maximum  $\Delta P$  to a value lower than the initial design due to mechanical strength of one component in the back-pulse system. Based on this requirement, a local pressure control valve was installed on each PCD back-pulse system, which cascades down the back-pulse pressure from the common header to the required value without affecting other systems. After lowering the maximum  $\Delta P$  setpoint, the back-pulse test was resumed for PCD FL1106. The pulse timer was increased from 50 ms to 75–175 ms range. The highest PCD outlet pressure was 521 psig. The test results are shown in Fig. 5.

The test results show that as the pulse timer increased, the mass discharge increased for all the PCD pressure tested. Unlike previous testing, the mass and volumetric discharges were comparable to the expected values. This trend confirmed that the back-pulse system was performing as designed and ready for on-coal operation.

Based on the functional check results for PCD FL1106, additional back-pulse tests were conducted for the two PCDs in Train B. Figs. 6 and 7 show the back-pulse mass discharges from the two Train B PCDs, FL2106 and FL2206, respectively. The tests were done during the system heat-up just prior to feeding coal. The PCD pressure was 42 psig. The back-pulse  $\Delta P$  was set at the medium level, and the back-pulse timer was set at 100 ms. In Figs. 6 and 7, the back-pulse valves are color-coded based on the associated accumulators.

As shown in the figures, the mass discharge varied significantly without regard to the accumulators. This pattern repeated itself in the back-pulse cycles indicating that each back-pulse valve was consistently acting uniquely. Initial thoughts were that the long and unequal length of the piping for the back-pulse valve actuation as well as variability in the back-pulse valve hardware might have been significant contributors to the difference. However, similar test for PCD FL1106 used local instrument

air bottles for valve actuation and only showed moderate improvement on the mass discharge amount, with significant mass discharge variation remaining. Therefore, the implementation of the local bottles on the other three PCDs were put on hold, and investigation began on addressing back-pulse valve hardware variability.

Despite the variation in back-pulse gas mass discharge, the absolute amount of the mass discharged was in the expected range based on performance data and experience gained from the PSDF PCD testing. Therefore, the online cleaning effect on the filter elements was satisfactory. A potential concern, however, was variation in the ash cake thickness on the filter elements from different clusters, since variation can affect syngas flow and ash deposit patterns, resulting in undesired long-term filtration performance. Further evaluation on filtration performance during coal feed was necessary.

The commissioning operations successfully tested major PCD subsystems with functional checks, control logic verification, and hardware inspection. Through the back-pulse tests, a detailed learning curve was established for this large scale CPP™ back-pulse system and the first application in coal gasification. The control system was fine-tuned to deliver required cleaning intensity to the filter elements. The PCD systems are now ready for on-coal startup operation.

During the commissioning period, several events in the PCDs occurred that required substantial repair and modification. The repairs were successful, but these events, as described below, affected overall commissioning schedule. Early in the commissioning, when the filter elements were installed, inspections discovered that there was no inlet pipe support beam in any of the PCDs, having not been installed in the fabrication facility. Consequently, the “L”-shaped inlet pipe was bent with part of the weight applied to the hanging support on the master tubesheet. In addition, some members of the hanging support were distorted and damaged that required repairs. Due to the space restrictions and limited access to the PCD cone, the beams had to be designed with a “split” configuration with a plate-bolt connection. Also, to fit the beams in the designed position, some inlet pipe sections had to be trimmed and re-welded. The newly added beams performed well without any issues.

Another inspection on the PCD clean side found a small crack on the flex seal in one PCD. The flex seal is a thin metal sheet component connecting the master tubesheet and the vessel wall to absorb thermal expansion of the master tubesheet, while sealing the gap with the vessel wall. The crack was in a weld seam in the flex seal and occurred due to a weld failure. Subsequent dye-penetrant tests revealed many cracks in the seal welds in all four PCDs, indicating that the flex seals were likely installed after the heads of the PCD vessels were in place which led to the various weld seams. The field inspection revealed there were 10–20 seams in each PCD rather than the three seams specified in the design. A repair plan added strip overlay on the weld seams to cover the cracks. Finite element analysis (FEA) was conducted to evaluate and fine-tune the stress and impact on the flexibility of the seals as the sole purpose of the seals is to seal the gap with certain flexibility to account for the thermal expansion differential between the master tubesheet and the vessel. The final repair was satisfactory in the subsequent operations.

Shortly after commissioning operation began, further inspections revealed that many blowback pots failed with top plates breaking away from the cylinders. The pot serves as a gas collection plenum above the modular tubesheet and distributes back-pulse gas to the filter elements. FEA evaluated the structural response of the pot under design specifications and showed the stress at the top plate-to-cylinder corner to be very high. The cornered weld structure and poor weld quality resulted in cracking at the weld. It eventually damaged the pot structure under

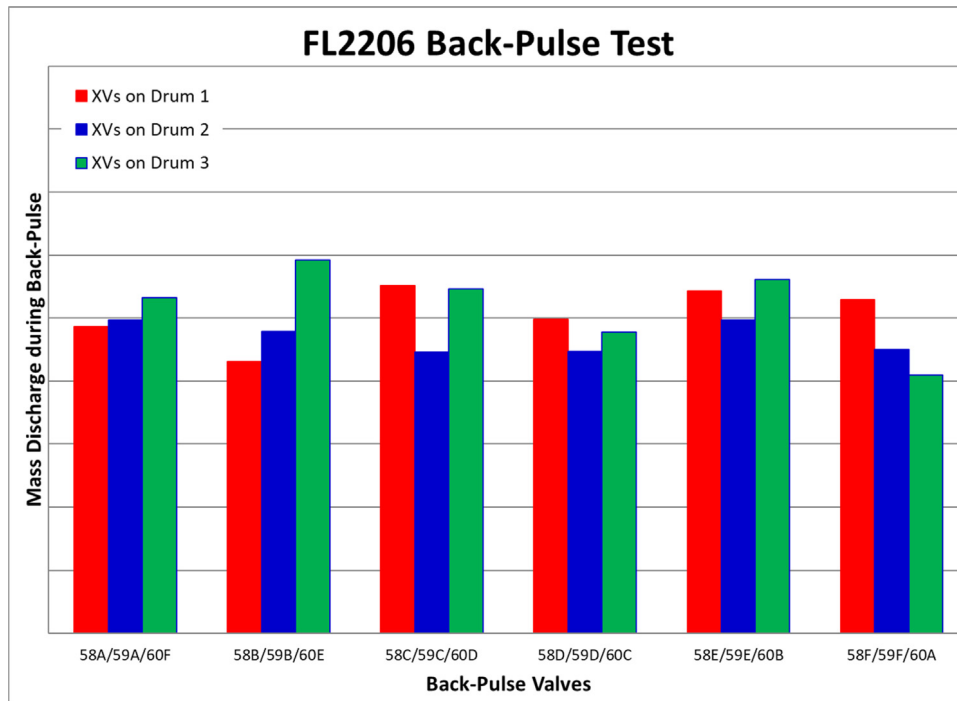


Fig. 7. PCD FL2206 back-pulse mass discharge.

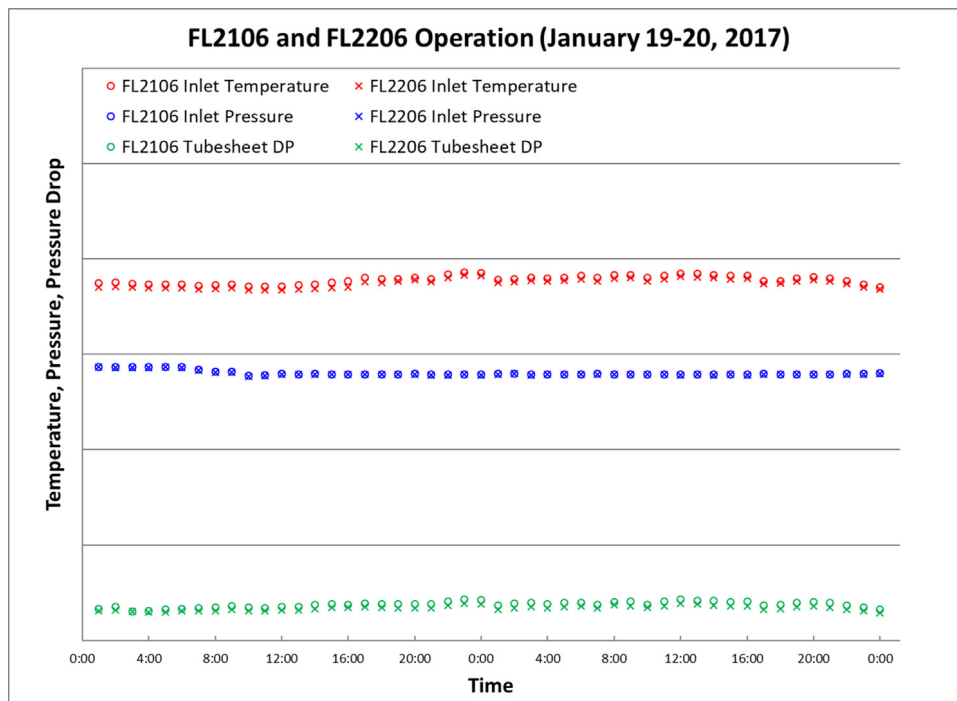


Fig. 8. Train B PCD operation in a two-day period.

repeated back-pulse pressurization. As a retrofit modification, different configurations of the pot structure were proposed, and FEA evaluated the stress and deformation. A cone-shape structure was finalized, fabricated, and installed. The retrofit was a success without further failures or negative impact on the back-pulse performance.

In the initial commissioning phase, the CFAD system and associated control logic was also functionally checked before the start of coal feed, when no fines were present in the system. The dry

checkout at Kemper emulated PSDF operations where the CFAD system operated for over 10 years with near 100% availability.

### 5. Operation and performance

With the first feeding of coal to the gasifier, syngas production at the Kemper facility began in 2016, with first coal feed to Train B in July and Train A in September. The on-coal operation in both trains continued until June 2017 when the lignite gasification portion of the plant was suspended. During the on-coal operation,



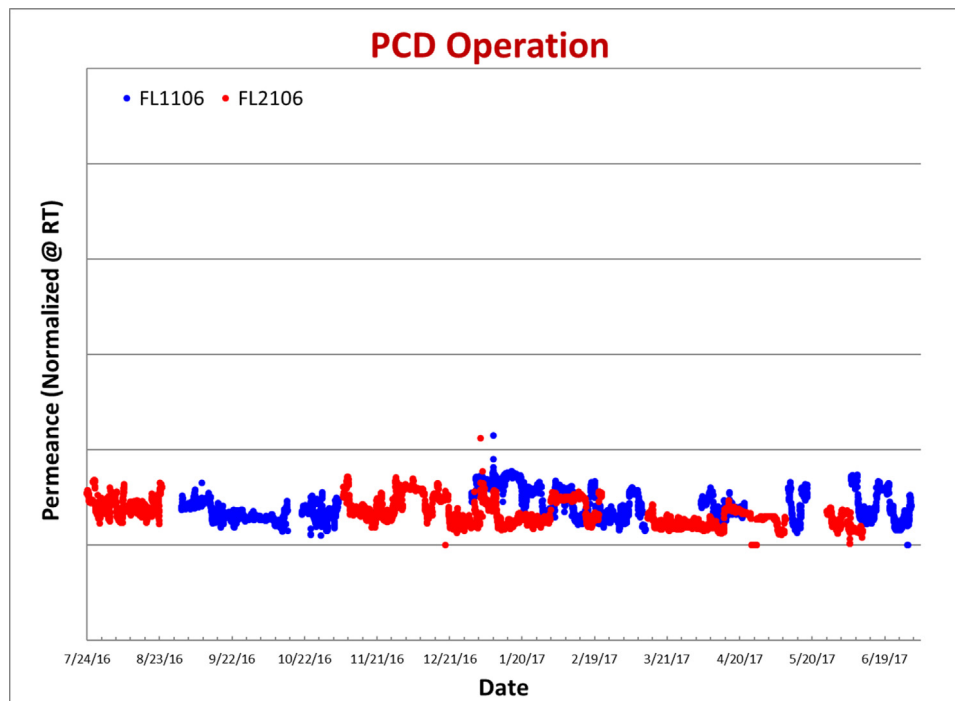


Fig. 9. PCD permeance in nearly one-year operation.

the PCDs functioned satisfactorily in filtration process. Fig. 8 depicts hourly data trends of major operating parameters for the Train B PCDs during a typical two-day period. The inlet temperatures and pressures varied slightly with gasifier operation. With the fine particulate loading in the raw syngas up to 30,000 ppmw (parts per million by weight), the PCD tubesheet pressure drop was low and relatively stable. The near identical operating parameters in both PCDs indicated that the syngas flows in the two PCDs were balanced in parallel paths.

For the normal operation, the continuous back-pulse mode was used. All of the 18 modules in each PCD were back-pulsed in one cycle of about 5 min. The back-pulse intensity was kept at medium  $\Delta P$  with 100 ms pulse timer. The filter element online cleaning was sufficient and consistent as indicated by tubesheet pressure drop trends and periodic inspections on the filter elements, while maintaining expected filtration performance. Overall, the 2.5 m long filter elements performed well without any filtration issues during lignite gasification operations at Kemper.

The 18 modules in the PCD resulted in no significant variation in the tubesheet pressure drop, since only one-eighteenth (5.6%) of the filter element surface area was back-pulsed at a given time. The overall tubesheet pressure drop was therefore largely unaffected by the back-pulse, a useful feature that reduced the impact of the pressure variation on upstream and downstream equipment.

The permeance of the filter elements defined by the ratio of face velocity to tubesheet pressure drop (permeance =  $FV/DP$ ) was relatively stable over nearly one-year of operation as shown in Fig. 9 (hourly data points). The variation of the permeance shown in the figure was due to changes in ash loading while the system was being started up and tested. The trend of the permeance is a good indication for the filtration performance of the filter elements. If the filter elements are not effectively cleaned, or if plugging or corrosion occurs in the filter element, the permeance decreases significantly over time. Ineffective cleaning leads to decreased filtration capacity and can lead to ash bridging between filter elements and potential damage to the filter elements.

In Fig. 9, the lower range of the data does not significantly decrease over extended operating periods, indicating good filtration performance. Consequently, the PCD filtration process never required a system shutdown throughout all gasification operations to conduct offline cleaning or replace elements damaged due to corrosion or plugging.

Normally, the PCDs remove nearly all the fine ash from the raw syngas. Based on PSDF experience, the FEAL filter elements used at Kemper are one of the most effective types of filter elements available with the highest particulate collection efficiency, achieving less than 0.1 ppmw particulate concentration at the PCD outlet. Although there is no direct measuring device for sampling the outlet particulate concentration at Kemper, there were no operating issues for the downstream processes with particulate fouling and erosion when the PCDs worked well to prevent dust leakage.

During syngas filtration, the PCDs experienced a few mechanical failures of some internal parts. In each case, the particulate presence was detected by the PCME continuous particulate monitor, with the elevated level of the PCME reading and its trend indicating the onset of the leak and its development. The particulate concentration was evaluated, referencing the calibrated curve established at the PSDF in a similar gasification process.

During two occasions, poor weld quality resulted in particulate leaking through a weld used to seal a fitting that routed thermocouple wire through the modular tubesheet. The leaks were small, allowing repairs to occur during scheduled shutdowns. In another leaking case, the seal material on one modular tubesheet flange failed. Again, the failed seal was replaced during the next scheduled shutdown, while noting design improvements for future systems to avoid similar failures. A third leak occurred during an abnormal operation when trouble-shooting the system. The high ash levels in the PCD cone damaged few filter elements. In this case, both high tubesheet pressure drop and elevated PCME reading indicated the high ash level and particulate leak. Again, the modules with failed filter elements were replaced in the next scheduled shutdown.

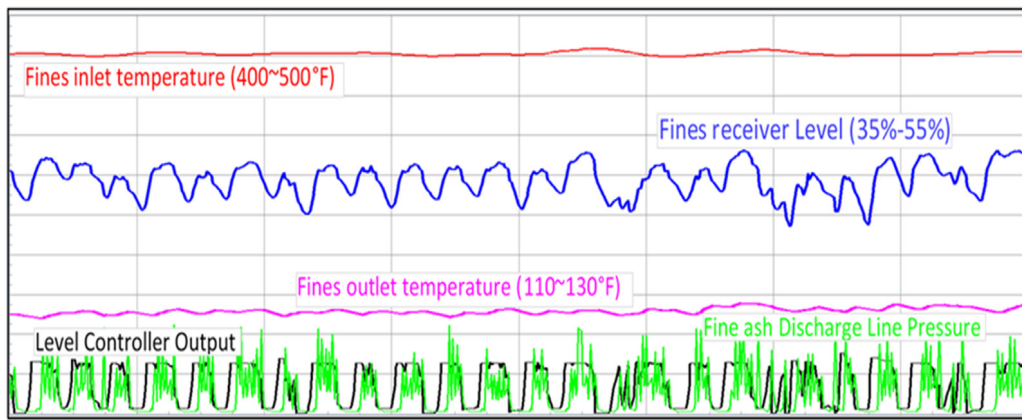


Fig. 10. Illustration of the performance of the CFAD system.

The CFAD system at Kemper experienced a learning curve typical of a first-of-a-kind technology. While the PSDF CFAD system had performed extremely well, with no major issues and near 100% availability in over ten years of operation (Various combustion and gasification, 0000), the Kemper CFAD system, on the other hand, experienced internal leakage in the PLDs due to mechanical integrity issues with the fabrication of non-standard inner screens needed for venting the gas entrained with the fine ash. Replacing the defective screens with standard screens that were stronger prevented the leaks. Before the replacement of the screens, the CFAD system could operate in an alternative mode, allowing for continued plant operations.

Fig. 10 illustrates the performance of the Kemper CFAD system. As shown in Fig. 10, the CFAD cooler (with cooling coils in the receiver vessel) consistently cooled the fine ash from the inlet temperature of 400–500 °F to 110–130 °F. Considering that the fines have a mean mass diameter of about 10–15  $\mu\text{m}$  and a bulk density of 10–15  $\text{lb}/\text{ft}^3$ , the fines cooler performed extremely well. Fig. 10 also shows that the discharge controller responded well to changes in level in the receiver vessel and maintained the fines level within a desired range. The operation was generally in batch mode, since the fines flow rate was low.

## 6. Inspections

During outages in operation, the PCDs were opened for inspection, repair, and modification. With repairs, modifications, and maintenance, the PCD mechanical components performed well. Visual inspections for the mechanical components revealed normal and sound integrity. Whenever opportunities existed, the filter elements were visually inspected for cake formation and appearance, and mechanical integrity of the hardware components. For the inspections, only the residual cake (permanent material not removed by back-pulses) was left after the shutdown rather than the residual cake plus the transient cake (ash build-up between back-pulses). After syngas filtration, the residual cake generally looked smooth and uniform along the length of the filter element (see Fig. 11 for a typical appearance). The residual cake was thin and fluffy with a color varying from black to tan, depending on the carbon content in the ash. There was no sticky material in the cake due to the absence of tar formation in the lignite gasification at Kemper, nor did any ash bridging or build-up occur between the filter elements or on the tubesheets. The inspections also revealed that there was no noticeable variation in the ash cakes among all the 18 clusters, confirming that variations in the mass discharge of the back-pulse gas did not cause

non-uniform ash cake formation as long as the absolute mass discharge was within the required range.

Offline cleaning was conducted for the removed filter elements with pressurized-water washing. The washed filter elements were heat-dried immediately afterwards. Most of the used filter elements showed near virgin appearance without corrosion. Some of them, particularly the ones near the inlet pipe inside the PCD, showed some surface corrosion. Visual inspection of these filter elements did not reveal any corrosion in the porous media. There was no particulate penetration or fouling inside the pores.

CFAD inspections also were important in evaluating its mechanical performance. After a few months of commissioning activities, the PLD inner screens failed primarily due to the type of inner screen selected during the design stage. However, the vendor had challenges in fabricating and delivering a larger non-standard screen with a smoother inner surface to aid fines flow. Similar units and other types of non-standard and standard screens from the vendor had been successfully and rigorously tested and were in operation for over ten years at PSDF with near 100% availability. At Kemper, the original PLD inner screens were replaced with a standard design with better structural strength. The repaired PLDs performed well during the period of operation after replacement. Even though the inner screens were compromised during the initial operation, the commissioning and integrated operation with coal feed to gasifier was able to continue unhindered with the CFAD system operating in an alternative mode.

## 7. Summary

The PCD commissioning proved the viability of a critical component in the TRIG<sup>TM</sup> gasification process at Kemper. Together with the rest of the Kemper IGCC plant, the PCDs and the CFAD systems were successfully commissioned after some repairs and modifications. The CPP<sup>TM</sup> back-pulse system was successfully tested over a wide range of the operating parameters and fine-tuned for syngas operation using a lower back-pulse pressure.

Overall, the PCDs performed well during syngas filtration. Stable filtration was achieved with up to design syngas production rates from gasifiers. The filtration capacity was sufficient and stable without significant degradation for an extended operating period, while the tubesheet pressure drop remained low and stable. The residual ash cake on the filter elements was thin and smooth with no ash bridging or build-up between filter elements.

The Kemper CFAD unit represented the first commercial scale version of the system developed and extensively tested at PSDF. Despite mechanical issues in the fabrication of PLD inner screens,



Fig. 11. Filter elements after an on-coal operation.

the CFAD system supported over 200 days of plant operations by successfully cooling the ash and depressurizing it from the system operating pressure.

Working together, the PCD and CFAD were able to support operation of the first commercial TRIG™ system, successfully filtering the syngas, while cooling and depressurizing the ash. While some modifications were necessary to improve availability and reliability of the systems, the design proved adequate. Future studies could extend the use of the combined system into other applications in gas filtration.

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