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FABRIC FILTRATION EXPERIENCE DOWNSTREAM FROM ATMOSPHERIC FLUIDIZED BED COMBUSTION BOILERS

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ABSTRACT

In recent years atmospheric fluidized bed combustion (AFBC) has become a commercially accepted technology for solid-fuel-fired power generation systems, with about 10 GWe of power generating capability either in operation or under construction. The continued development and commercialization of AFBC technology has also included evaluations of balance-of-plant systems, including particulate control methods, required to support a power generating system. These evaluations have included research on the physical and chemical characteristics of AFBC fly ash. Results of this research show AFBC fly ash to be generally more difficult to handle than pulverized coal (PC) fly ashes.

As part of their research efforts to support the development of particulate control technology for the utility industry, EPRI has evaluated the performance of electrostatic precipitators and baghouses downstream of AFBC boilers. EPRI has recently completed studies of fabric filtration during two utility AFBC demonstration plant projects in Colorado and Kentucky. Also completed recently is a worldwide survey of pulse-jet baghouses including those applied to both utility and industrial AFBC boilers.

Results from these studies are presented in this paper. These data include baghouse performance data (air-to-cloth ratio, pressure drop, emissions, bag life), as well as information on baghouse operation and maintenance experience including startup and shutdown procedures, common maintenance problems, etc. These data show that although there is still some uncertainty as to the exact interaction of AFBC ash characteristics and filtration performance, the overall experience of plants employing fabric filtration has been good.

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INTRODUCTION

In recent years atmospheric fluidized bed combustion (AFBC) worldwide has increased sharply - about 10 GWe of generating capacity is currently either in operation or under construction. The advantages of this technology for new plant construction, retrofit at older plants, and plant life extension have motivated this increased interest. In the retrofit area alone, EPRI estimates that 20,000 MW of pulverized-coal (PC) boilers are candidates for AFBC retrofits (1). Besides the utility market, there are a number of small AFBC boilers installed around the world for the purpose of process steam generation or co-generation.

Key advantages of AFBC (bubbling bed and circulating bed) technology include reduced SO_2 and NO_x emissions, compared to those of PC boilers, as well as the possibility of utilizing a wide variety of fuel sources (coal, peat, culm, bark, wood waste, hog fuel, etc.). However, AFBC particulate emissions may tax conventional particulate control systems.

In electrostatic precipitators (ESP), AFBC ash is more difficult to collect than PC ash because AFBC coal ash has a higher electrical resistivity and the use of cyclones (multiclones) for recycling, inherent with the AFBC process, tends to reduce exit gas stream particle size. In the case of fabric filters, the effects of AFBC ash characteristics on filtration performance have been difficult to estimate because of limited experience. For both ESPs and fabric filters the high particulate mass concentration exiting AFBC boilers (typically two to four times higher than PC boilers) can also provide an emissions control challenge.

In spite of these concerns, the general particulate control experience of AFBC plant operators has been favorable, especially in cases where fabric filtration has been used. This paper reviews the status of fabric filtration applied to AFBC boilers. Current fabric filter control technology is discussed, the unique filtering characteristics of AFBC ash are presented, and baghouse performance, operation, and maintenance issues are highlighted. Specific performance data from EPRI's two AFBC Demonstration Plant baghouses are included.

UNIQUE CHARACTERISTICS OF AFBC FLY ASH

Some of the features of the AFBC process have a direct bearing on the particulate properties that most strongly influence baghouse performance in terms of filtering pressure drop (2). Operating at temperatures in the range of 1500-1600°F, an AFBC boiler does not reach the ash fusion temperature as does a PC boiler at 2200-2500°F. As a result, AFBC combustion of coal forms irregularly shaped fly ash particles compared to the spherical PC fly ash particles formed by melting and condensation.

The co-combustion of coal and limestone in most AFBC boilers yields a distinctly different fly ash chemistry than that of PC ash. The high alkalinity of the AFBC ash alters the cohesivity and, consequently, the porosity or thickness of the dustcake, or both. The AFBC process also involves inertial segregation of the fly ash with cyclones (multiclones) in order to recycle the larger particles through the furnace to improve fuel and sorbent utilization. This recycling decreases the mean diameter of the ash particles that are passed to the fabric filter. These small particles tend to create a dustcake structure with a high intrinsic pressure drop.

Figure 1 compares the range of values for several physical properties of AFBC fly ash to those for PC and spray dryer residue ashes. These data form part of the EPRI Fabric Filter Database. Specifically called out in the figure are the values for ashes from the two EPRI AFBC Demonstration Plants. These plants are the Colorado Ute Electric Association's (CUEA) 110-MWe Nucla Unit 4 located near Nucla, Colorado and Tennessee Valley Authority's (TVA) 160-MWe Shawnee Unit 10 located near Paducah, Kentucky. The Nucla facility has a circulating bed AFBC boiler and the Shawnee facility has a bubbling bed AFBC boiler. Data for fly ashes from the TVA 20-MWe AFBC Pilot Plant and the Texas/New Mexico 150-MWe TNP Unit 1 are also presented in this figure.

On average, the AFBC particles are smaller in size, have higher specific surface area, and higher porosity relative to PC ashes. Although the higher porosity of AFBC ash helps to compensate for the smaller particle size and higher surface area, the net effect is higher pressure drop attributable to the small pore diameters within the dustcake caused by the small, irregularly shaped particles. For comparable residual dustcake areal densities, AFBC dustcakes will have a higher inherent pressure drop than PC dustcakes at the same filtering air-to-cloth ratio. Even though AFBC residual dustcakes tend to be lighter (lighter bag weights) compared to PC dustcakes, the bag cleaning methods employed must be energetic enough to maintain a low residual dustcake areal density. This will insure a low to moderate operating pressure drop. This is demonstrated in Figure 2 which shows the effect on baghouse performance at the TVA 20-MWe AFBC (bubbling bed) Pilot Plant when the bag cleaning method was changed from reverse gas to reverse gas with sonic assistance (3). The filtering air-to-cloth ratio was doubled without a pressure drop penalty.

CURRENT FABRIC FILTRATION EXPERIENCE

The use of AFBC worldwide has increased dramatically as the technology has become more widely accepted and commercialized at the industrial-sized level. Over 150 units are in operation or under contruction with sizes ranging up to 165 MWe. Except for two of the larger utility AFBC units, all of the remaining AFBC boilers worldwide use fabric filtration for final flue gas cleanup.

There are two major types of fabric filters, low ratio and high ratio. Low ratio baghouses typically operate with filtering air-to-cloth ratios in the range of 1.5 to 3.0 ft/min and employ one of three different bag cleaning methods: reverse gas, reverse gas with sonic assistance, and shake/deflate. High ratio baghouses generally operate with filtering air-to-cloth ratios in the range of 3.0 to 5.0 ft/min and use one of three pulse-jet cleaning methods: high pressure/low volume (40 - 100 psi), intermediate pressure/intermediate volume (15 - 40 psi), or low pressure/high volume (5 - 15 psi) (4). Traditionally in the United States pulse-jet cleaned baghouses have been used most commonly on smaller industrial-sized AFBC units where the flue gas volume to be cleaned is small and the small size and site area common to the units make them attractive. Typically, the larger utility AFBC installations in the U.S. use low-ratio baghouses that employ the more gentle bag cleaning methods, although, as has been noted above, more agressive cleaning methods are generally required with AFBC ash in order to control residual dustcake buildup in the bags and correspondingly high pressure drops.

Over the past several years, EPRI has conducted baghouse performance evaluations at both full-scale and pilot-scale fabric filters downstream from AFBC boilers and has surveyed fabric filter applications on industrial and utility AFBC boilers around the world in order to assess baghouse performance characteristics and create a database of operating data to be used in predicting fabric filter performance (5)(6). Figure 3 summarizes the performance of several types of fabric filter installations downstream from AFBC boilers. These data demonstrate that fabric filters are able to maintain reasonable pressure drops at typical filtering air-to-cloth ratios and that the more energetic cleaning methods (shake/deflate and pulse-jet) are best for maintaining low pressure drops at high air-to-cloth ratios.

The database of information from these plants also indicates that both low-ratio and high-ratio baghouses with the proper bag fabric can maintain emission levels at or below regulatory limits. Table 1 summarizes the baghouse performance experience at a representative selection of AFBC baghouses worldwide. EPRI has recently completed extensive evaluations of two full-scale, low ratio fabric filter installations at their AFBC Demonstration Plants in Colorado and Kentucky; performance data from these units has been included in Figure 3 and Table 1. A more detailed review of the fabric filter installations is presented below.

LOW RATIO FABRIC FILTRATION

CUEA Nucla 110-MWe AFBC (circulating bed) Demonstration Plant

The Nucla Station originally consisted of three 12-MWe stoker-fired boilers. In 1974, in order to meet more stringent emissions regulations, a baghouse was installed downstream from each boiler. These three, six-compartment, shake/deflate cleaned baghouses (Units 1, 2, and 3) were built by Wheelabrator-Frye. In 1984 it was decided to retrofit the Nucla Station with an AFBC boiler to replace the three stoker boilers. To accomodate the additional gas flow generated by the new 110-MWe boiler, Research-Cottrell was contracted to build a new baghouse to supplement the three older baghouses. The new twelve-compartment baghouse (Unit 4) also uses shake/deflate cleaning. Figure 4 shows the general layout of the four baghouses in relationship to the boiler house. Table 2 presents the design data for the fabric filter system.

Fabric Filter System Performance. The baghouses were placed in service in July 1987 and accumulated over 12,500 hours in service during the demonstration project that ended in June 1990. Two sources of coal were burned during this operating period (Salt Creek and Peabody). Considering the new boiler technology on which they were applied, the Nucla baghouses have had a very good performance record, comparable to other full-scale utility baghouses downstream from pulverized-coal boilers. There have been no periods of uncontrollable high pressure drop, and the shake/deflate cleaning system, in general, has worked well in cleaning the bags, maintaining low bag weights, and controlling pressure drop under a variety of coal and sorbent feed rates.

An extensive baghouse evaluation was performed on the new (Unit 4) baghouse after approximately 9500 hours of service. This baghouse was able to provide a low mass emission rate (0.007 lb/MBtu (no bag failures)) at a fairly high filtering air-to-cloth ratio (2.4 to 2.9 ft/min) with low to moderate tubesheet (3.7 to 5.2 in. H_2O) and flange-to-flange (5.0 to 6.5 in. H_2O) pressure drops at near full-load conditions. The shake/deflate cleaning system was able to maintain low bag weights (0.23 lb/ft^2 residual dustcake areal density) even though the inlet particulate concentration was high (8.9 gr/dscf) compared to values typically experienced at baghouses downstream from utility pulverized-coal boilers (7).

Figure 5 compares the performance of the Nucla Unit 4 baghouse with baghouses located downstream from other utility AFBC boilers. Figure 6 compares Nucla Unit 4 baghouse performance to data from full-scale utility baghouses downstream from pulverized-coal boilers. In both instances the Nucla baghouse performance compares quite favorably.

Filter Bag Performance. The filter bags used at Nucla were constructed from a 10 oz/yd^2, woven fiberglass fabric with a nominal 10% Teflon B finish. Fabric integrity was generally good during the 12,500 hours of operation during the demonstration project, except for failures associated with fabric abrasion near the bottom of the bag.

Beginning at about 4500 hours of service and for the next 8000 hours of operation, the baghouses at Nucla experienced 377 bag failures (out of 4176 total bags installed), the majority of which were due, either primarily or secondarily, to ash abrasion on the lower two feet of bag fabric just above the tubesheet. Ash abrasion at this location occurred because the bags are mounted inside the thimbles and sealed in place with snap bands sewn into puckered bottom cuffs. The resulting pleats and folds in the fabric are exposed to the ash-laden flue gas passing into the bags. Our theory is that the abrasion problem was compounded by ash that accumulated between the opening in the tubesheet and the outside surface of the bag as a result of the poor snap band/cuff seal to the thimble. This accumulation of ash forced the fabric further into the gas stream. Figure 7 illustrates the ideal snap-band bag attachment versus the actual situation occurring at Nucla. Utility baghouses normally have bags attached on the outside of the thimbles that are mounted on the top of the tubesheet.

Of these bag failures, 82% occurred in the Unit 2 baghouse. It was determined that the large number of early bag failures in the Unit 2 baghouse was exacerbated by overdeflation (also occurring in the Unit 1 and Unit 3 baghouses, but to a lesser extent) and by the fact that most of the shaker mechanisms in this baghouse were working properly (causing additional stress to the abraded fabric). Adjustment of the deflation flow rate and the replacement of the failed bags led to a substantial decrease in the rate of bag failures in the three older baghouses. Figure 8 shows the total number of bag failures for each of the last seven quarters of baghouse operation during the demonstration project (the first bag failures were found during the third quarter of 1988).

In the spring of 1990 a recommendation was made to CUEA to install a compartment of new bags modified to reduce fly ash abrasion on the bottom of the bags. The modification incorporated the installation of an anti-collapse ring approximately eleven inches above the bottom of the bag. The purpose of the anti-collapse ring was to limit the movement of the fabric into the flue gas stream entering the bag (especially during resumption of filtering after a cleaning sequence when the bags are normally collapsed due to deflation and shaking), thus reducing the likelihood of abrasion in this region of the bag. The modified bags have been in service about 7500 hours. No bag failures have occurred to date.

On two occasions during the demonstration project, bags were removed from the baghouse and submitted for strength testing and evaluation. This was done after 5,000 and 11,000 hours of operation. Also, a new, unused bag was submitted to determine its properties for comparison to the used bags. For the bags in service for 11,000 hours the Mullen Burst strength averaged 302 lb/in^2, a 49% loss from the average value for the unused bag (592 lb/in^2). This compares to 362 lb/in^2, a 39% loss, for the bags tested after 5,000 hours of service. Fiberglass fabric normally loses a significant fraction of its original strength during the intial period of service (up to 2,000 hours), then the rate of loss tapers off to a gradual decline with continuing service under stable operating conditions. Figure 9 graphically shows the behavior of the Mullen Burst values over the first 11,000 hours of service. It was determined from this and other data that the current (11,000 hour) level of strength retention was still quite serviceable, and that bag life could easily be extended to 25,000 hours; assuming no losses from abrasion and if filtration characteristics of the fly ash remain acceptable.

TVA Shawnee 160-MWe AFBC (bubbling bed) Demonstration Plant

The TVA Shawnee Steam Plant originally consisted of ten, 175-MWe pulverized-coal boilers. Flue gas cleanup equipment consisted of a ten-compartment, reverse-gas cleaned, fabric filter following each boiler (installed 1979 - 1981 by General Electric Environmental Services, Inc.). Following the successful completion of the test program at TVA's 20-MWe AFBC (bubbling bed) Pilot Plant at Shawnee (3), a new 160-MWe AFBC (bubbling bed) boiler was constructed adjacent to the old Unit 10 pulverized-coal boiler. The Unit 10 PC boiler was shut down and the original turbine and fabric filter were then used in conjunction with the new AFBC boiler. In the mid-1980s the Shawnee baghouses were retrofitted with sonic horns to supplement the normal reverse-gas cleaning system. Figure 10 shows the general layout of the Shawnee plant. Table 3 presents the design data for the fabric filter system.

The Unit 10 baghouse began filtering AFBC fly ash during the third quarter of 1988. Through August 1991 the baghouse has accumulated over 12,500 hours of service. The Shawnee Unit 10 baghouse has had a very good performance record, comparable to the other nine PC baghouses at Shawnee. There have been no periods where boiler operation has been limited by baghouse pressure drop, and the sonic-assisted reverse-gas cleaning system has worked well in controlling pressure drop and maintaining moderate bag weights.

The baghouse has provided particulate emission rates less than the current EPA New Source Performance Standard (NSPS) of 0.03 lb/MBtu while operating with no bag failures. At full-load conditions and at a moderate filtering air-to-cloth ratio (1.6 ft/min) the baghouse has operated at a moderate flange-to-flange pressure drop of 8.0 in. H_2O with reverse-gas cleaning and 6.5 in. H_2O with reverse-gas cleaning with sonic assistance. The sonic-assisted, reverse-gas cleaning system has been able to maintain moderate bag weights (0.55 lb/ft^2 residual dustcake areal density) even though the inlet mass concentration has been high (unmeasured) compared to values typical for pulverized-coal boilers.

Figure 11 compares the flange-to-flange pressure drop performance of the Shawnee Unit 10 baghouse during several operating periods. Until July 1990 the baghouse operated with reverse-gas cleaning only. As can be seen in this figure, this low energy cleaning method was not able to control pressure drop. At full-load conditions the pressure drop increased from 5.1 in. H_2O (May - Sept 1989) to 7.0 in. H_2O (Oct 1989 - Feb 1990) to 8.0 in. H_2O (June 1990). In July 1990 the sonic horns were placed in service for the first time. By August 1990 the pressure drop had stabilized at about 6.4 in. H_2O. In late 1990 new horns (same fundamental frequency, more powerful (based on the manufacturers specifications)) were installed in each of the baghouse compartments. Although the new horns were able to reduce, on average, the residual dustcake areal density from 0.78 to 0.55 lb/ft^2, there was not a significant improvement in pressure drop. As of July and August 1991 the pressure drop was still about 6.5 in. H_2O at full-load conditions. The important point to consider, though, is that pressure drop has been stabilized through the use of the more energetic reverse-gas cleaning with sonic assistance.

Figure 5 compares the performance of the Shawnee Unit 10 baghouse with low-ratio baghouses located downstream from other utility AFBC boilers. Figure 6 compares Shawnee Unit 10 baghouse performance to data from full-scale, low-ratio utility baghouses downstream from pulverized-coal boilers. In both instances the Shawnee baghouse performance compares favorably.

HIGH RATIO FABRIC FILTRATION

The pulse-jet (high ratio) fabric filter performance data for the ten units listed in Table 1 represent both domestic and overseas plants. These baghouses are operating on relatively small bubbling bed and circulating bed boilers (11.5 to 55 MWe). High pressure/low volume pulse-jet cleaning is most common among the ten units. Both woven glass and needlefelts (Ryton and Nomex) fabrics are used in these pulse-jet facilties; however, the woven glass is of a heavier weight (16 to 22 oz/yd^2) compared to typical woven glass fabrics for low-ratio baghouses (10 to 14 oz/yd^2). These heavier woven glass fabrics are better able to withstand pulse forces and abrasion. These heavier, woven glass fabrics are able, in most cases, to simulate needle felts, for which, contrary to the case for low-ratio collectors, reliance for filtering is placed on the fabric and not the dustcake. The data indicate that, on average, at the time of the visits to these sites, the units were operating at air-to-cloth values of about 3.0 ft/min. Although two of the units were designed for air-to-cloth values of about 4.5 ft/min, none of the ten units were operating with air-to-cloth values in the range of 4.0 to 5.0 ft/min.

As shown in Figure 3, except for one plant, the flange-to-flange pressure drops are moderate, similar to values for the low-ratio baghouses. These data suggest that pulse-jet fabric filters (PJFFs) can operate at air-to-cloth ratios up to two times higher than those of conventional reverse-gas baghouses without a pressure drop penalty. The potential reduction in plan area requirement can result in pulse-jet baghouse dimensions which are as little as 1/2 to 2/3 of that needed by a conventional low-ratio baghouse. This can be an important consideration for retrofit applications where there are spacial limitations.

The particulate emission rates for these fabric filters are very good, averaging well below 0.02 lb/MBtu. Bag life has been fair to good for these plants, ranging from 1 to 3 years. As noted in Table 1, several plants have had bag failures due to a variety of problems including abrasion, SO_3 attack, and misaligned pulse pipes. In some cases bag life has been increased by the use of lower air-to-cloth values requiring less frequent pulse cleaning. Overall, there appears to be no operating limitations due to selection of pulse cleaning pressure or fabric type, or application on bubbling or circulating bed boilers.

A worldwide survey of pulse-jet baghouse performance funded by EPRI and the Canadian Electric Association (6) has revealed that the concern that pulse-jet baghouses have inherently high maintenance costs is unfounded. Large utility, PC boiler installations of PJFFs are currently in place in other parts of the globe, and they have not demonstrated such problems, provided reliable and sturdy components are used and intelligent design and fabrication details are observed.

An attractive aspect of pulse jet baghouses is the potential retrofiting of pulse-jet cleaned baghouse modules within old electrostatic precipitator (ESP) casings. This is particularly attractive to utilities considering plant life extension by replacing their old PC boilers with an AFBC boilers. If the old plant were originally equipped with an ESP, it can be cost effective to install pulse-cleaned modules within the ESP box. Longer bags (in excess of 20 feet in length) have been successfully applied in pulse-jet cleaned baghouses (6). The use of long bags reduces plan area requirements and often is essential for this type of retrofit into ESP casings.

Ultimately, the selection of one type of baghouse technology over another can be made only after the options have been compared on a technical and economic basis for the site specific conditions. Not only must capital cost be evaluated, but also significant operating and maintenance costs, such as filter bag replacement, must be considered. The imposition of an ultralow emissions limitation theoretically might require a low-ratio baghouse. However, the worldwide survey (6) indicates, as noted previously, that PJFFs can provide outlet emissions performance at levels comparable to low-ratio baghouse technologies at well below the NSPS of 0.03 lb/MBtu.

STARTUP AND SHUTDOWN PROCEDURES

A critical factor for baghouses is the adherence to proper startup and shutdown procedures. The performance of a filter bag is sensitive to the bag's history, and improper procedures followed during startups and shutdowns can affect the performance of the cloth for its life. The primary concern for any boiler application is protecting the fabric from moisture and acid condensation brought about by dewpoint excursions during startups as well as the deposition of hydrocarbons from oil combustion during startup. The use of auxiliary fuels during startups for lengthy periods of bed heat-up and other operational quirks make such procedures even more important for an AFBC baghouse.

The procedure recommended by most baghouse manufacturers and followed at most of the sites visited (6) is the precoating of any new fabric prior to startup and/or admitting any flue gas to that fabric. Many different substances are used, such as inert fly ash, pulverized limestone ($CaCO_3$), diatomaceous earth, and hydrated lime ($Ca(OH)_2$) (not pebble lime, quicklime, or lime (CaO) that is not hydrated). In any event, the precoat material must be coarser than the ash or dust to be filtered and must be inert and not react (in a harmful way) with moisture, acids, or other flue gas constituents to form a dustcake that becomes sticky, breaks down, hardens, or in other ways becomes difficult to remove.

In AFBC units auxiliary fuels must be burned to preheat the bed material prior to adding coal to the boiler. In heating the limestone, its calcination process begins and unhydrated lime will carry over to the baghouse. Additional moisture results from burning gas or oil, which, in combination with reacted or unreacted lime, can produce a tenacious dustcake on bags that have not been protected with a precoat. Many sites in North America use the shovel method to load the inert precoat through hatches in the ductwork while the ID fans are in operation. European operators typically use a precoat system which makes the process easier and perhaps more uniform. Many sites, and especially those in Europe that operate seasonally, precoat as part of every major shutdown for the season and prior to the startup for a new season.

The importance of developing proper startup and shutdown procedures is exemplified by the experiences of two pulse-jet fabric filter installations. Their problems related to unexpected acid-dewpoint excursions resulting from carbon-catalyzed dissociation of calcium sulfate during slumped-bed operation (8). At the first site, premature failure of felted Nomex bags was traced to temporarily high levels of SO_x. At the other site, relatively high levels of SO_x at low gas temperatures resulted in deposition of these acids on the filter cake, with the resulting reaction causing a hard, impermeable dustcake to develop on the Ryton needlefelt bags.

During shutdowns at the first site with the Nomex bags, the PJFF was normally left on-line since, once coal firing ceased, the baghouse could be purged with hot air from the boiler. However, early in the plant's history, temporary short-term shutdowns were occasionally required for numerous reasons. Typical SO_2 concentrations during normal operation were at the 110 ppm level. However, the plant discovered that very high SO_2 levels, on the order of 500 ppm, could occur for periods up to 5 hours or longer when the bed was slumped during these temporary shutdowns. These excursions in SO_2 concentration were occurring during periods when moisture and acid would condense on the bags because of the low gas temperature. These conditions eventually were determined to be the cause of acid attack on and premature failure of the Nomex bags.

The plant developed a theory as to why the SO_x excursions occurred. During the slumped bed condition, the bed remains hot, and consists mainly of burned and unburned coal and primarily spent sorbent ($CaSO_4$). Without the addition of fresh sorbent, the SO_2 concentrations in the flue gas would soar. This was not perceived, initially, to be a problem since the plant's SO_x limits are in terms of pounds per day, and their overall daily emission limit would not be significantly affected, since despite the high concentration in the flue gas, the volume of the flue gas was quite low at 5 to 15% of the full-load volume. It was theorized that in the hot reducing atmosphere of the slumped bed dissociation of the calcium sulfate occurred, thus generating the high SOx concentrations. Since discovering the problems associated with such a slumped bed mode of operation, the plant has started to add limestone to the bed during periods of temporary outages.

During the startup and early operational period at the second AFBC unit, achieving efficient carbon burnout of the fuel proved difficult. Analyses of ash carryover to the pulse-jet baghouse indicated loss on ignition (LOI) figures typically above 30% and often as high as 50%. Eventually, pressure drop across the baghouse climbed until the unit had to be shut down. To resolve the immediate high pressure drop problem, the Ryton filter bags were removed and cleaned off-site by means of a gentle washing cycle in industrial washing machines. These bags subsequently were hung to dry. Testing of the washed fabric revealed an increase in permeability and a 25% increase in outlet emissions when compared to new bags. However, the original emissions were quite low and the result was that the plant was still in compliance with its limitations. Reasonable pressure drops were restored to this facility.

Initially it was suspected that the numerous, long-term startups encountered in the plant's early operating phase on natural gas resulted in excessive moisture excursions. However, theory and investigations eventually indicated that the high carbon in the recycled ash and spent/unspent sorbent mixture acted as a catalyst to dissociate the calcium sulfate into its components during the numerous slumped bed periods. The resulting relatively high emissions of SOx at low gas temperatures resulted in deposition of these acids on the filter cake. The chemical reactions within the dustcake caused a hard, impermeable ash layer to develop on the bags. Subsequent efforts to permanently solve the problem have been aimed at reducing LOI values, with some success.

SUMMARY

Fabric filtration has worked well on both industrial and utility-sized AFBC boilers. Fabric filtration has been applied to AFBC boilers up to 165 MWe in size. While the physical and chemical properties of the AFBC fly ash cause this ash to be somewhat more difficult to handle, properly designed fabric filtration systems providing adequate bag cleaning energy have worked well in maintaining low to moderate filtering pressure drops without a degradation in outlet emission rates. With proper attention to baghouse design, fabric selection, startup and shutdown procedures, and other O&M considerations, bag life has been good. Evidence of good performance by fabric filters downstream from AFBC boilers in a full-scale utility setting has been provided at EPRI's Nucla and Shawnee Demonstration Plants, and at pulse-jet facilities worldwide.

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Table 1. AFBC Baghouse Design and Performance Data

#	Plant	Location	Type	MWe	Design Flowrate (acfm)(000)	Cleaning Method	Fabric	Design Air-to-Cloth Ratio (ft/min)	Measured Air-to-Cloth Ratio (ft/min)	F-F Pressure Drop (in. H2O)	Tubesheet Pressure Drop (in. H2O)	Particulate Emission Rate (lb/MBtu)
1	Utility (Pilot)	USA (KY)	Bubbling	20	109	RG	14 oz Woven Glass	1.5	0.6-1.3	2.3-7.5	2.1-6.7	<0.03
1	Utility (Pilot)	USA (KY)	Bubbling	20	109	RG/S	14 oz Woven Glass	1.5	1.0-2.0	2.0-6.7	1.8-6.0	<0.03
2	Utility	USA (KY)	Bubbling	160	513	RG	10 oz Woven Glass	1.6	1.5	8	6.1	<0.03
2	Utility	USA (KY)	Bubbling	160	513	RG/S	10 oz Woven Glass	1.6	1.5	6.5	4.6	<0.03
3	Utility	USA (CO)	Circulating	110	215	SD	14 oz Woven Glass	2.4	2.4-2.9	5-6.5	3.7-5.2	0.007
4	Utility	USA (TX)	Circulating	150	650	SD	10 oz Woven Glass	2.2	2.15	4.25	3.5	0.008
5	Chemical Plant	Japan	Bubbling	11.5	87	PJ (IP/IV)	Nomex	4.2	3.57	5.6	-	0.0041
6	Manufacturing Plant	Japan	Bubbling	-	59	PJ (LP/HV)	Nomex	2.97	3.29	-	2.36	0.0057
7	CoGen Facility	USA	Circulating	55	203	PJ (HP/LV)	22 oz Woven Glass	3.6	3.98	9.4	7.3	0.0064
8	CoGen Facility	USA	Bubbling	19	91	PJ (HP/LV)	Nomex	3.2	-	-	-	0.0168
9	CoGen Facility	USA	Bubbling	19	91	PJ (HP/LV)	Ryton	3.2	3.56	4.5	2.8	0.0185
10	Refinery	USA	Bubbling	-	145	PJ (HP/LV)	16 oz Woven Glass	4.5	2.6	4.8	3.5	-
11	Steam Plant	USA	Circulating	-	182	PJ (HP/LV)	22 oz Woven Glass	3.2	2.7	4.7	3.3	0.0019
12	CoGen Facility	Germany	Circulating	37	111	PJ (HP/LV)	Ryton	4.6	3.4	6.8	-	0.0114
13	Power/Heating	Germany	Bubbling	41	161	PJ (IP/IV)	Nomex	3.6	1.8	2.41	1.41	0.0095
14	CoGen Facility	Germany	Circulating	48	165	PJ (HP/LV)	Ryton w/ glaze	3.94	2.37	6.02	-	0.0095

NOTE: RG - Reverse Gas Cleaning
RG/S - Reverse Gas Cleaning with Sonic Assistance
SD - Shake-Deflate Cleaning
PJ - Pulse Jet Cleaning

(Source: References 3, 5, 6, 7)

Table 1. AFBC Baghouse Design and Performance Data (continued)

#	Plant	Location	Type	MWe	Bag Life (yrs)	Expected Life (yrs)	Comments
1	Utility (Pilot)	USA (KY)	Bubbling	20	4	4	Not currently in operation
1	Utility (Pilot)	USA (KY)	Bubbling	20	4	4	Not currently in operation
2	Utility	USA (KY)	Bubbling	160	1+ (FBC)	5+	Bags originally installed in mid-1980s for PC boiler
2	Utility	USA (KY)	Bubbling	160	1+ (FBC)	5+	New horns installed last quarter of 1990
3	Utility	USA (CO)	Circulating	110	2+	4+	Fabric abrasion (tubesheet area) on some bags
4	Utility	USA (TX)	Circulating	150	1+	4+	Very good performance record to date
5	Chemical Plant	Japan	Bubbling	11.5	2.5+	3	-
6	Manufacturing Plant	Japan	Bubbling	-	1+	3	Sand only in bed
7	CoGen Facility	USA	Circulating	55	1.25+	-	Dust abrasion due to flow distribution
8	CoGen Facility	USA	Bubbling	19	1.5	-	Abrasion-misaligned pipes/SO3 attack
9	CoGen Facility	USA	Bubbling	19	1+	-	-
10	Refinery	USA	Bubbling	-	2.8+	-	4+ years but at low cap. factor, 2.8 service yrs so far
11	Steam Plant	USA	Circulating	-	1+	-	-
12	CoGen Facility	Germany	Circulating	37	1.25+	-	Bags washed in machine
13	Power/Heating	Germany	Bubbling	41	1.13	2	-
14	CoGen Facility	Germany	Circulating	48	1.17+	-	-

(Source: References 3, 5, 6, 7)

Table 2

DESIGN INFORMATION FOR THE CUEA NUCLA AFBC BAGHOUSES

	Baghouse #1, #2, & #3	Baghouse #4
Baghouse manufacturer	Wheelabrator-Frye	Research-Cottrell
Number of compartments per baghouse	6	12
Bags per compartment	112	180
Bag size	8 in. x 22 ft.	8 in. x 22 ft.
Bag manufacturer and model number	Fabric Filters #504	Fabric Filters #504
Bag fabric	3 x 1 twill, warp out,	3 x 1 twill, warp out,
Bag fabric finish	10% Teflon B	10% Teflon B
Bag cleaning method	Shake/deflate	Shake/deflate
Cloth area per bag	44.31 ft^2	44.31 ft^2
Cloth area per compartment	4,963 ft^2	7,976 ft^2
Cloth area per baghouse	29,778 ft^2	95,712 ft^2
Total cloth area	185,046 ft^2	
Design filtering air-to-cloth ratio, for all 30 compartments and full-load flow of 414,000 acfm	2.24 acfm/ft^2 (gross) 2.50 acfm/ft^2 (net) 2.76 acfm/ft^2 (net-net)	
Bag cleaning initiation	Pressure drop	Pressure drop
Bag cleaning set point	5.0 in. H_2O (slow mode) 6.0 in. H_2O (fast mode)	6.0 in. H_2O (slow mode) 7.0 in. H_2O (fast mode)
Compartment cleaning frequency	360 s (slow mode) 10 s (fast mode)	360 s (slow mode) 10 s (fast mode)
Compartment cleaning sequence	Null (25 s), Deflate (45 s) Shake (5 s, 15 s after deflation starts), Null (15 s)	Null (25 s), Deflate (45 s) Shake (5 s, 15 s after deflation starts), (Null 15 s)
Deflation air-to-cloth ratio	0.3 acfm/ft^2	0.3 acfm/ft^2
Shake frequency	4 Hz	3 Hz
Shake amplitude	1 in.	1 in.
High pressure drop alarm	7.0 in. H_2O	8.0 in. H_2O
High pressure drop bypass	No bypass available	9.0 in. H_2O
Bag tension	60 lb	60 lb
Compartment isolation available	Yes	Yes
Compartment vent system	No	Yes
High inlet temperature bypass	No bypass available	320°F
Low inlet temperature bypass	No bypass available	180°F
Hopper size per compartment	98 ft^3	230 ft^3

Table 3

DESIGN INFORMATION FOR THE TVA SHAWNEE AFBC BAGHOUSE

	Unit 10
Baghouse manufacturer	Buell-Envirotech (GEESI)
Number of compartments per baghouse	10
Bags per compartment	324
Bag size	12 in. x 35 ft.
Bag manufacturer and model number	Fabric Filters, Midwesco, W.W. Criswell
Bag description	3 x 1 twill, warp out, 9% Teflon B, 14 oz/yd^2
Bag cleaning method	Reverse-gas w/sonic assistance
Cloth area per bag	108 ft^2
Cloth area per compartment	34,992 ft^2
Total cloth area	349,920 ft^2
Design filtering air-to-cloth ratio, based on full-load flow of 472,000 acfm	1.63 acfm/ft^2 (net)
Bag cleaning initiation	Pressure drop
High pressure drop alarm	Yes
High pressure drop bypass	Yes
Bag tension	75 lb
Compartment isolation available	Yes
Compartment vent system	Yes
High inlet temperature bypass	Yes

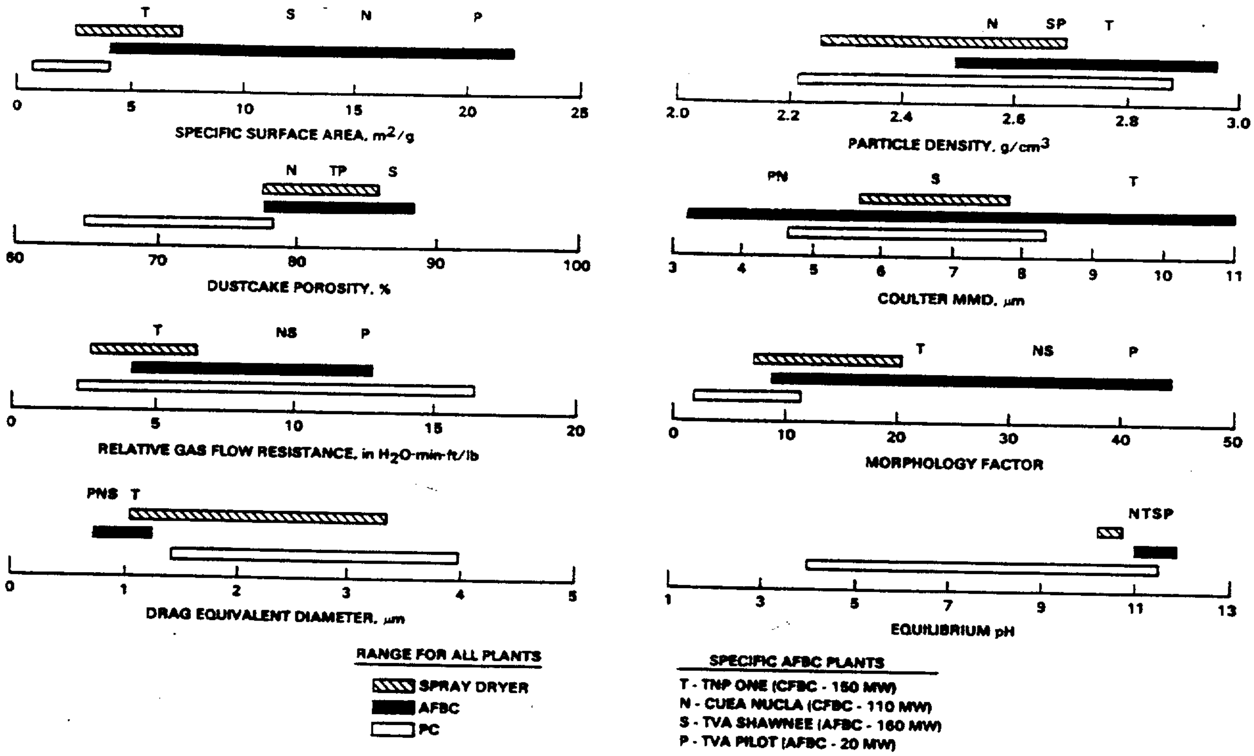

Figure 1. Range of values for eight physical properties of dustcake ashes in the EPRI Fabric Filter Database. Data for four AFBC plants are highlighted.

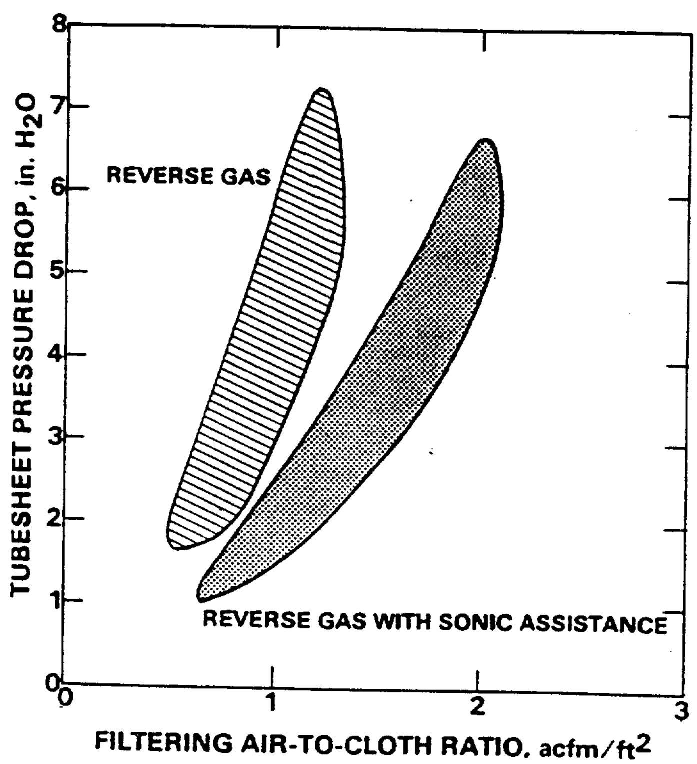

Figure 2. Comparison of tubesheet pressure drop versus filtering air-to-cloth ratio at the 20-MW TVA AFBC Pilot Plant baghouse for reverse-gas cleaning and reverse-gas cleaning with sonic assistance.

AFBC Baghouses Worldwide

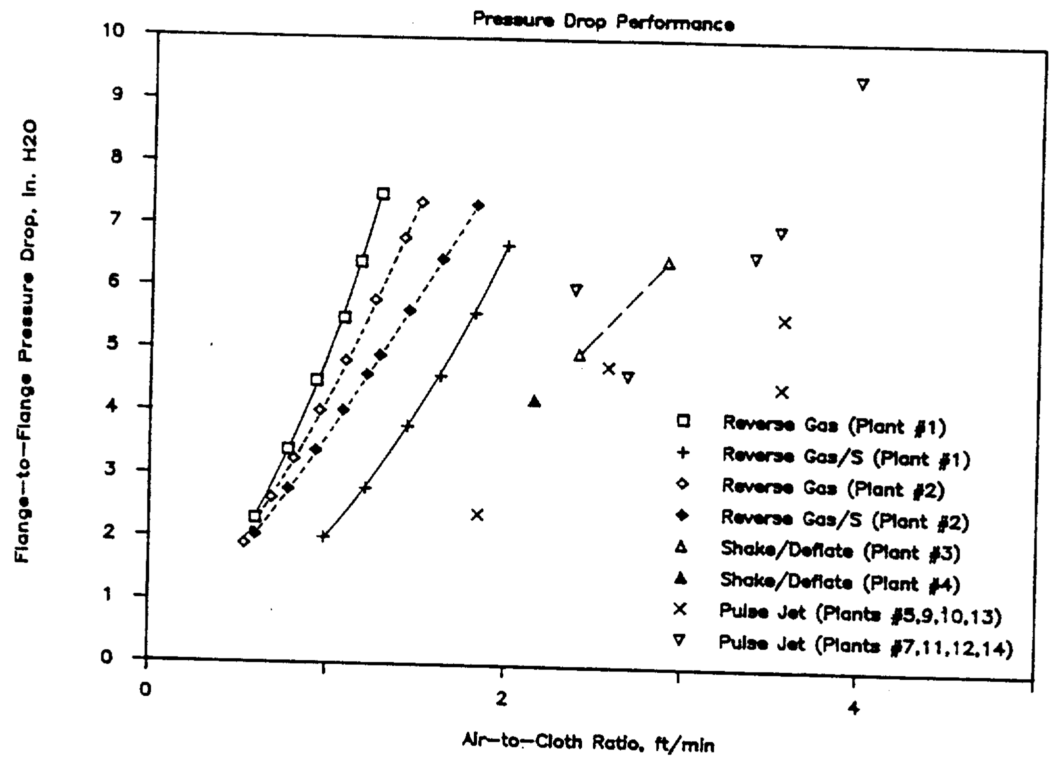

Figure 3. Pressure drop performance versus air-to-cloth ratio for several AFBC fabric filters worldwide. See Table 1 for key to plant identification.

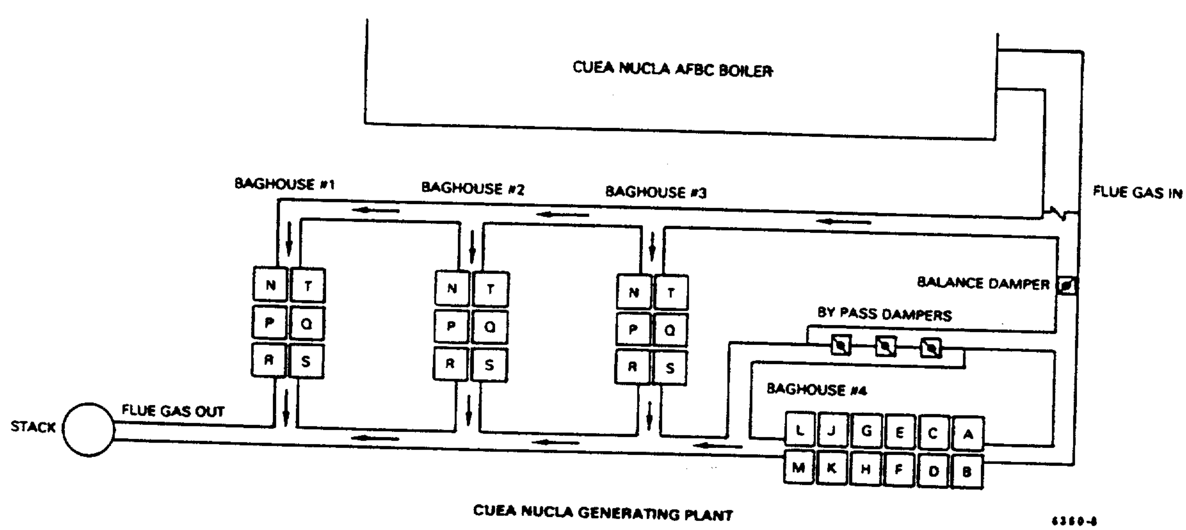

Figure 4. General layout of the four fabric filter units at the CUEA Nucla 110-MW AFBC (circulating bed) Demonstration Plant.

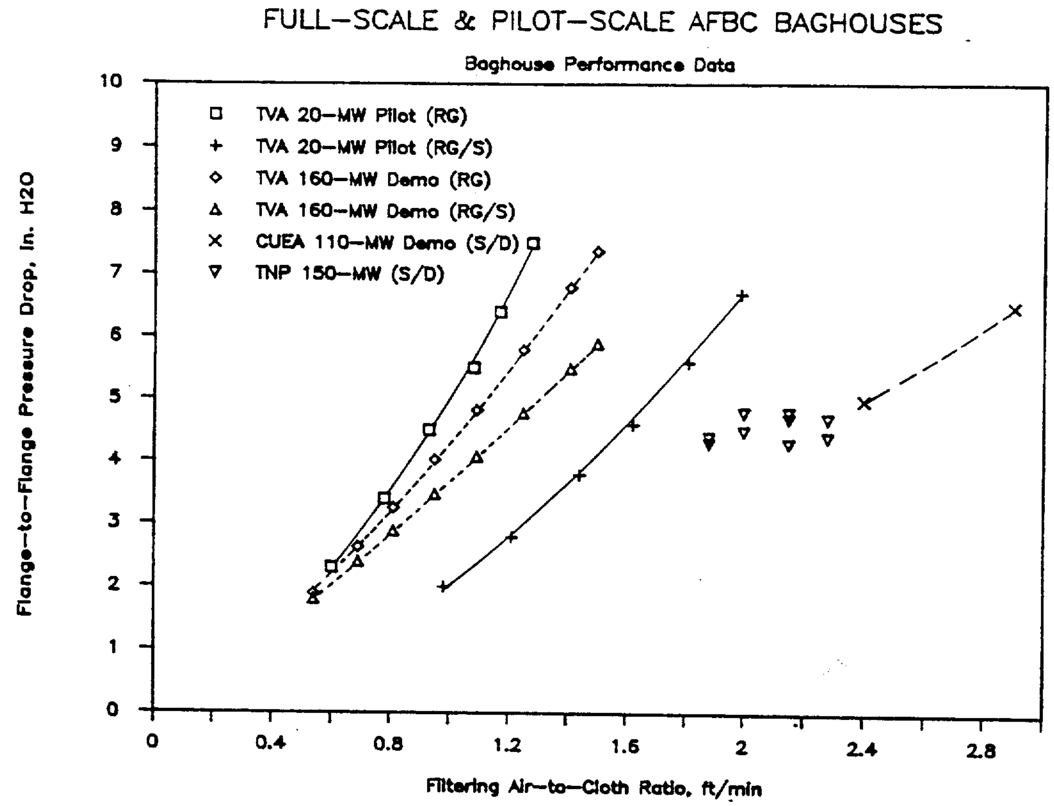

Figure 5. Performance data for fabric filters downstream from four U.S. utility AFBC boilers.

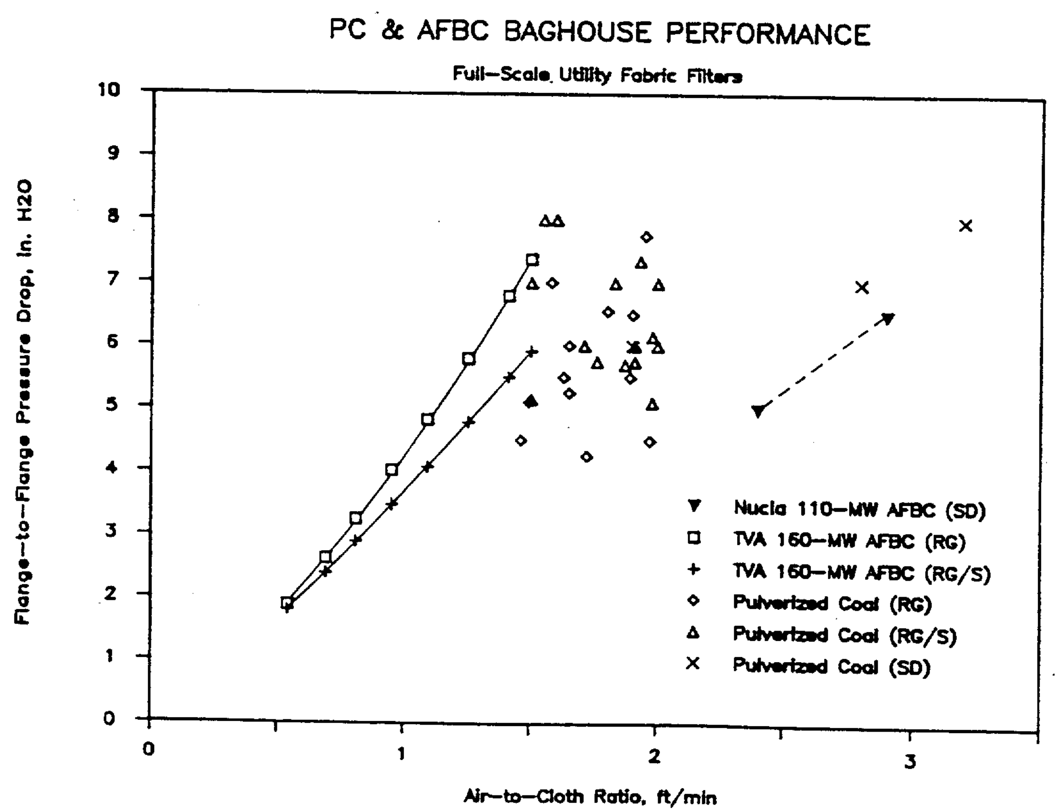

Figure 6. Comparison of baghouse performance at the two EPRI AFBC Demonstration Plants and a variety of pulverized-coal utility boilers.

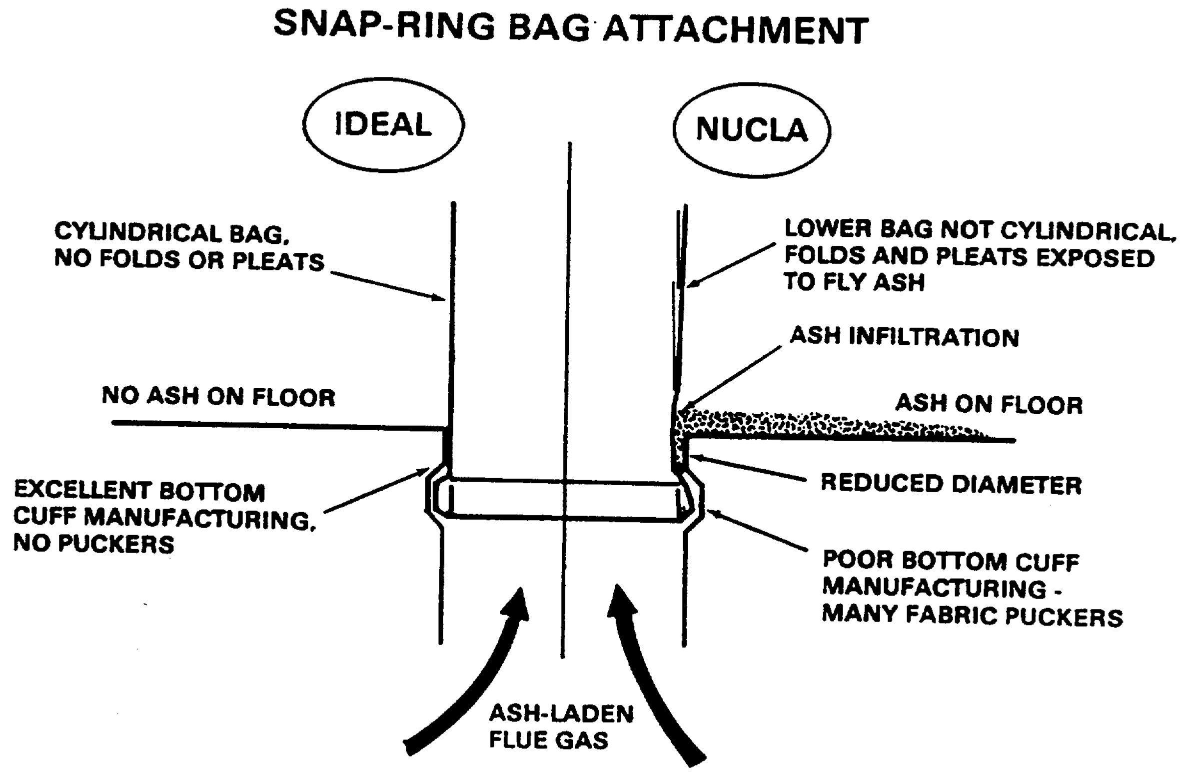

Figure 7. Schematic drawing showing ideal snap-ring bag attachment and actual snap-ring attachment experienced at the CUEA Nucla Demonstration Plant baghouse.

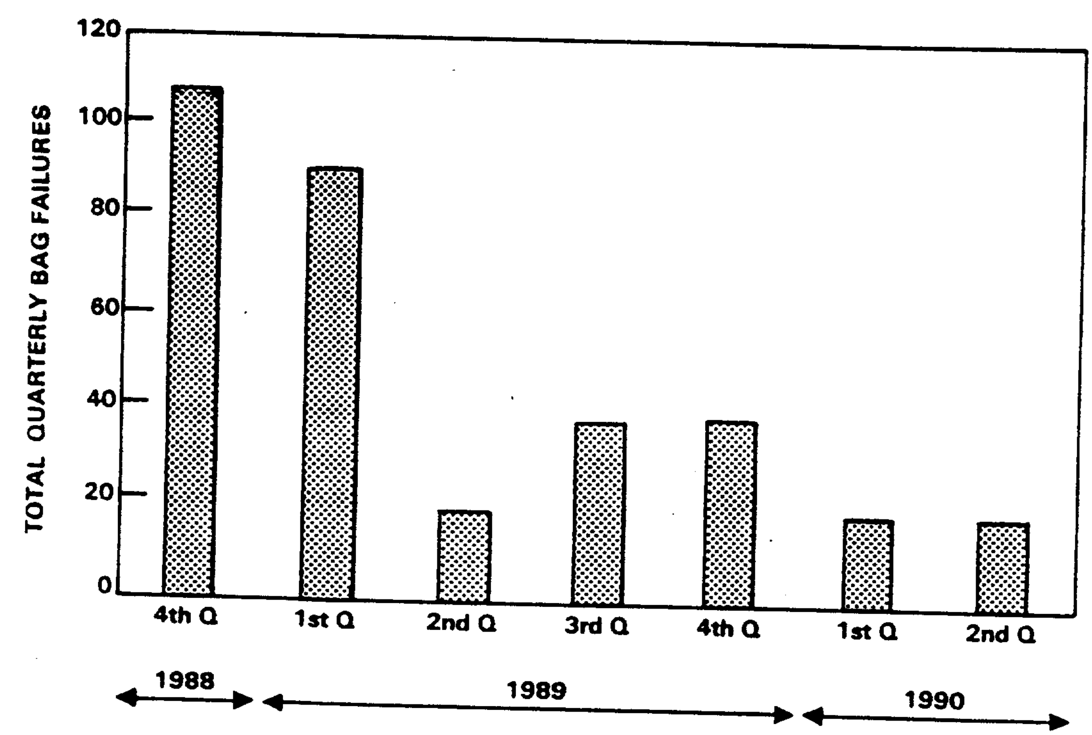

Figure 8. Number of bag failures per quarter for the last seven quarters of baghouse operation during the CUEA Nucla Demonstration Plant project (October 1988 through June 1990).

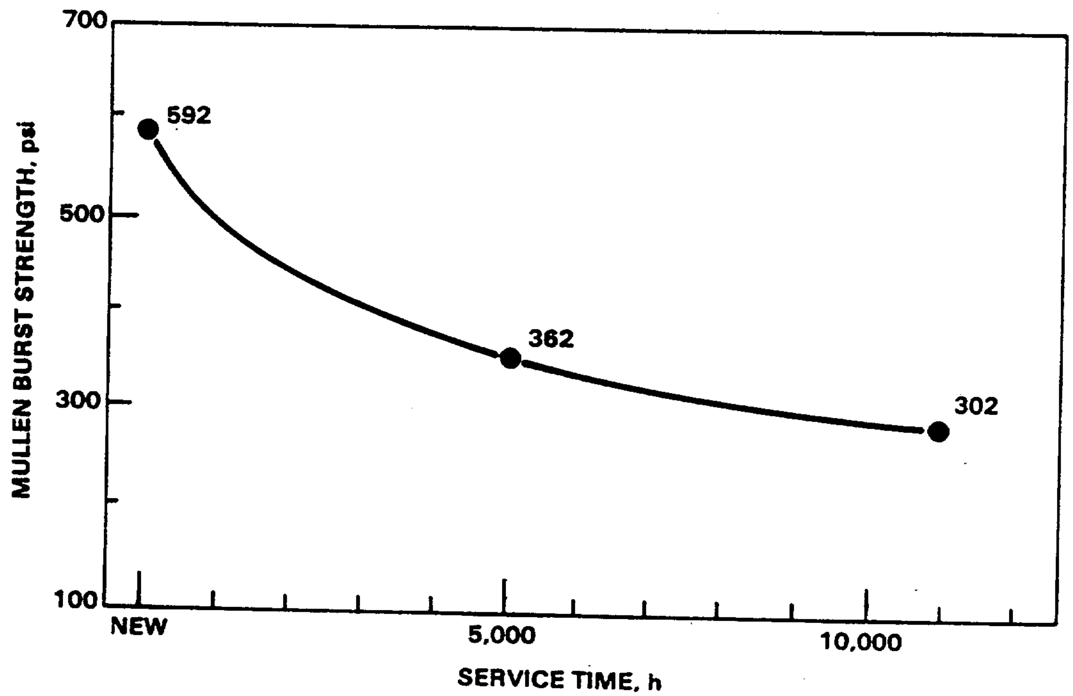

Figure 9. Effects of service time on Mullen Burst strength of fabrics from the CUEA Nucla Demonstration Plant baghouse.

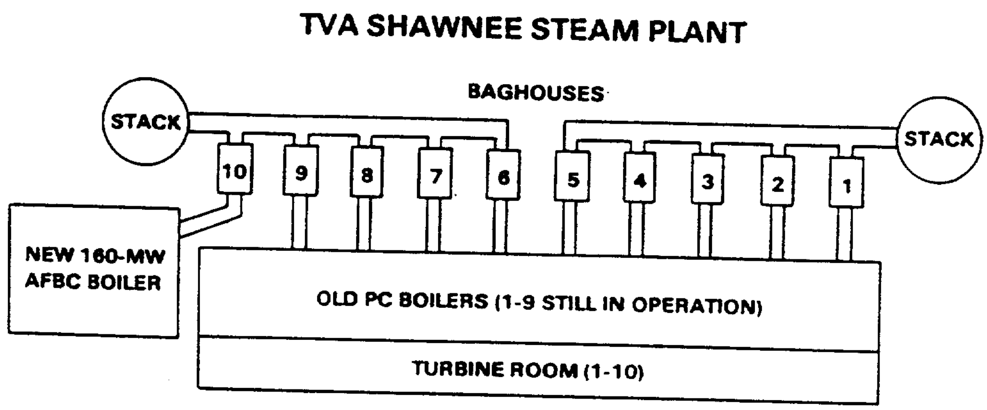

Figure 10. General layout of TVA's Shawnee Fossil Steam Plant. Unit 10 is the new 160-MW AFBC (bubbling bed) Demonstration Plant.

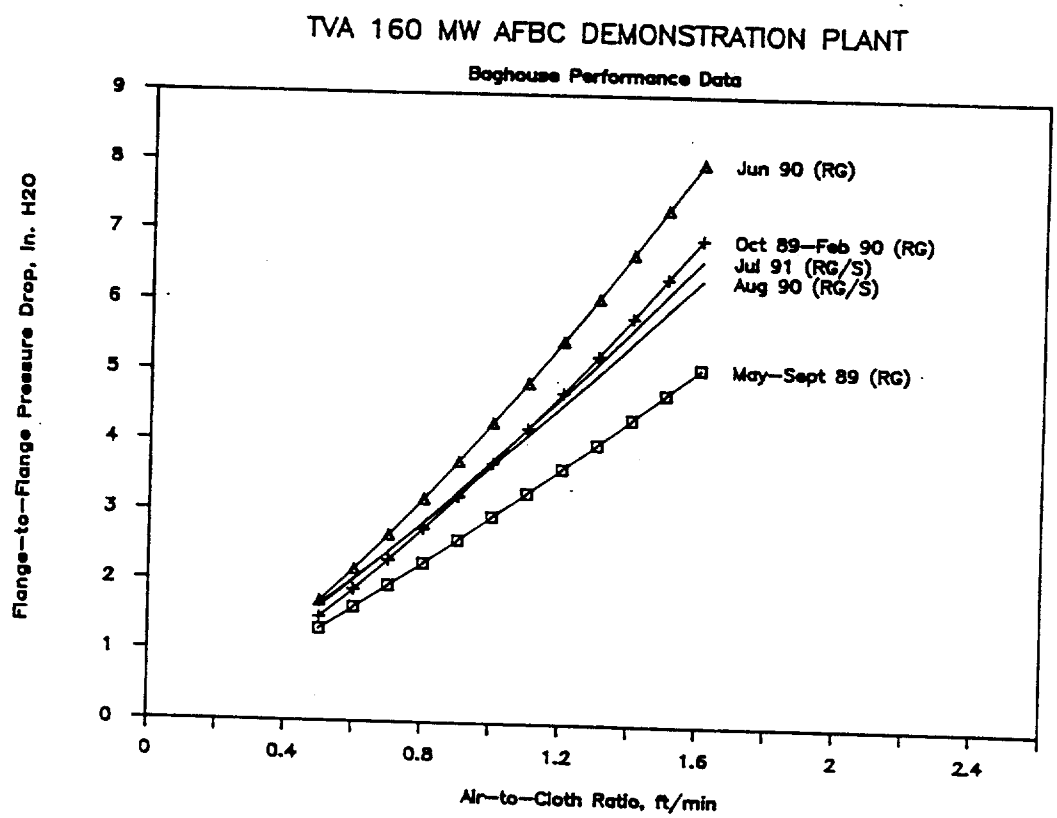

Figure 11. Baghouse performance data for the TVA Shawnee AFBC Demonstration Plant during five operating periods, three with reverse-gas cleaning and two with reverse-gas cleaning with sonic assistance.