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**CE IGCC Repowering Project
Char Filters**

**Topical Report
November 1990 - May 1993**

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May 1993

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References

- Reference I "Ceramic Filters for High Temperature Service" by T. Tompkins, K. Hsieh, L. White, & D. Johnson, 3M Corp, presented at Industrial Applications of Advanced Ceramics - II, Los Angeles, Ca., Nov 21, 1991**
- Reference II Memtec America Corp., 1750 Memtec Drive, DeLand, Fl. 32724-2045**
- Reference III "Choose the Right Ceramic for Filtering Hot Gases" by Paul Eggerstedt & J. Zievers, Chemical Engineering Progress magazine, January 1993**

INTRODUCTION

ABB CE is participating in a coal gasification combined cycle repowering project that will provide a nominal 60 MW of electricity to City, Water, Light, and Power (CWL&P) in Springfield, Illinois. The major systems consist of CE's air-blown pressurized entrained flow two-stage gasifier, an advanced hot gas clean up system, a combustion turbine adapted to use low BTU gas, a heat recovery boiler, a steam turbine/generator island, and a coal handling yard.

The hot gas clean up system consists of a system of high temperature high pressure char filters upstream of an advanced high temperature high pressure gas desulfurization system. Char is the particulate matter in the product gas leaving the gasifier process, and consists primarily of carbon and ash. The char filters separate the char from the product gas discharging it to the char recycle system for reinjection into the gasifier. The clean product gas exits the char filters at high temperature and goes to the desulfurization process. This Topical Report describes the current state of design for the char filter system, and is the first topical report addressing the char filters.

The project is currently in the second budget period of five. The major activities during this budget period are:

- Establishment of approved for design (AFD) engineering package.
- Development of a detailed cost estimate.
- Resolution of project business issues
- CWL&P renewal and replacement activities.
- Application for environmental air permits.

1.0 SUMMARY OF RESULTS

In early 1991 work commenced on the development of a high temperature high pressure char filter for the Springfield Repowering Project. ABB CE developed performance parameters for the filters, searched the literature for available technologies, and worked closely with suppliers of hot gas filters to produce a workable design that would integrate well into the gasifier process, physical arrangement, and operation. Because of the emerging nature of hot gas filtration media and technology, this design incorporates the flexibility to use several types of filter media and the ability to perform on line maintenance by using two or more filter modules. Cleaning requirements, the effects of corrosive product gas, and filter service life cannot be defined with any accuracy at this point without further development testing of the filter media. Test work is planned, but has not been funded or started as yet. Finalization of the char filter design will be delayed as long as possible to allow the incorporation of test results, and any applicable new developments in this rapidly evolving technology. High temperature high pressure gas filtration is still a high risk and costly technology, but one that is ready for demonstration.

2.0 DESCRIPTION OF CHAR FILTERS

The char filters are required to operate at 1000 degrees f at a nominal internal pressure range of 256 to 294 psia. These operating conditions require filter design and media on the cutting edge of gas filtration technology. Because the available technology is in an early and intense stage of development, the char filter system design for this project, although workable, is in a continual state of evolution and has not been finalized. The description that follows is the system design used for the development of the detailed project cost estimate, and is depicted in figure 1. Alternate design options under consideration are discussed later in this report.

In the design used for estimating the demonstration plant, product gas and entrained char leave the gasifier heat exchanger at 1000 degrees f and enter a char cyclone that separates a nominal 65% of the char from the product gas. The product gas and remaining char discharge the cyclone to two parallel char filters each sized to handle 50% of the gas and char load. The char filters resemble conventional cylindrical bag filter modules use for gas filtration. The product gas enters the lower portion of the filter vessel above the conical hopper and below the filter media. The gas inlet design is configured to promote char drop out and even distribution of dirty gas to the filter assemblies. The hopper is designed for mass flow, and incorporates steam tracing to maintain sufficient temperatures during start ups and shut downs and fluidizing nozzles for use as discharge aids during upset conditions. The hopper is not intended for storage of char, but as a chute to continuously channel the char by gravity to the common char receiving bin located below the char filters. The 12ft. diameter vessels are constructed of carbon steel with insulating refractory linings. The refractory in the cones is lined with stainless steel to promote flow. The filters are designed to use any of three different high temperature filter media:

- Nextel, a woven ceramic
- sintered inconel metal filters
- ceramic candle filters

This feature permits the possible demonstration of any of these filter media, and allows substitution of one media for another with little alteration to the char filters, and minimal expense. Each of the above filter media is cylindrical in shape and is hung from the tube sheet with sufficient spacing to allow the build up of a 1/2" char cake on its o.d.. Each type of filter is available in common diameters, and the tube sheet is arranged for a single filter diameter. It is planned to use perforated stainless steel tube inserts for the Nextel and sintered metal filters to insure filter durability, and the ability of the filter elements to withstand high pressure differentials. Each char filter is sized for a 3 to 1 or less ratio of gas (acfm) to filter area (sq ft) for each type of media.

The tube sheet is designed to accommodate movement and stress due to thermal expansion and differential pressure excursions. Normal pressure differential across the tube sheet should be in the range of 1 to 5 psi. The char filters use a jet pulse type cleaning system utilizing superheated steam as a cleaning media. It is estimated using char permeability data from other gasifier projects that each filter will have to be pulsed every 3 to 6 minutes at design conditions. A jet venturi is located above each filter, and several filters are pulsed simultaneously. The pulsing valves are solenoid type valves designed specifically for steam service. These valves and their associated fittings are located outside the vessel, and are arranged for easy access.

The vessels incorporate walk in plenums above the tube sheet to permit easy inspection and removal of the filters from the tube sheet. Facilities are also provided to get filter components up to and down from the char filters. Triboflow particle detectors are placed in the product gas discharge piping of each char filter to detect and alarm filter failures. The Nextel and metal filters also allow the option of placing fuse elements at their gas exits that would blind in the event of a filter failure and prevent carryover to the desulfurization system. If enough filters fail in this arrangement, the differential filter pressure will go high enough to indicate a failed condition. It is possible to isolate a damaged filter for repair while allowing the other char filter and gasifier to remain in operation at reduced load. However, this arrangement would require the gasifier to be shut down relatively briefly (2 to 3 days) to do so.

The char filters were incorporated into the design of the gasifier process for several reasons:

1. The high temperature zinc titanate desulfurization system can tolerate only trace carryover of char particles. Because over half of the char particles are less than 20 microns in size, cyclones are not feasible in this application to achieve the level of filtration required. The primary function of the cyclone in the design for the estimate is to reduce the pulsing frequency required to control pressure differential across the char filters. Alternate char filter system designs may eliminate the need for the cyclone, however.
2. Char filters permit virtually all the char to be recycled back to the gasifier. This results in negligible carbon loss, and no flyash to be collected or disposed of.

3. The zinc titanate desulfurization system requires temperatures in excess of 800 degrees f to be effective. This operating temperature is above the range of conventional high temperature gas filter media, and requires the use of cutting edge filter materials.

3.0 METHODOLOGY

The total consumption of char is one of the many process advantages incorporated into the ABB CE air entrained gasifier concept. The timing of this process design coincided with the emerging technology of high temperature gas filtration and desulfurization. Hot gas filtration and desulfurization offer significant reductions in power plant emissions while allowing very high thermal cycle efficiencies. Because integrated gasification combined cycle (IGCC) is being developed as the fossil fuel power plant technology for beyond the year 2000, it is appropriate to use and develop hot gas filtration in this demonstration project.

The first step in the design process was to establish the operating parameters for the char filters. This was done through a combination of calculation, gasifier gas flow and temperature modeling, and extrapolation of operating data from the CE atmospheric air entrained process development unit and other gasification pilot plants. Operating parameters are listed in appendix I (confidential).

After preliminary operating parameters for the char filters were established, the available options for filter media able to operate at 1000 degrees f were studied by searching the literature and making inquiries to suppliers of hot gas filtration systems. Initially, woven ceramic bags, ceramic candles, ceramic tubes, and sintered metal filters were studied. Preliminary proposals for char filter systems were received in early 1991 from Acurex

Environmental Corp., Westinghouse Science and Technology Center, Mikropul Environmental Systems, Industrial Filter and Pump Mfg. Co., and Babcock & Wilcox. The proposals were quite varied in approach to filter media, cleaning methods and media, and filter arrangement. Initial cost estimates for the char filter system varied widely also. An evaluation process studied and compared these proposals in an effort to narrow down the selection of filter media and filter system design. During this period, the ceramic filter materials were undergoing testing and development. Because the rigid type ceramic filters were experiencing structural problems, and sintered metal filters seemed to have inherent corrosion problems with sulfidation, Nextel woven ceramic bags by 3M Corp. were focused on. At 1000 degrees f, the Nextel bags allowed a conventional approach to the filter arrangement, and they were producing promising test results. During this time, ABB CE developed a filter design philosophy to guide our development program for this system component. This document was submitted to the DOE and is included in this report as Appendix II.

Another round of more specific inquiries went out in 1992 to the same suppliers requesting Nextel as the filter media. Proposals came back from Acurex and Westinghouse using Nextel, and from Mikropul using sintered inconel filters. The filter arrangements were still quite different, as were the requirements for cleaning and the costs. Each proposal was reviewed in depth with each supplier, and follow up proposals were requested. During these meetings, it became quite obvious that it would be necessary to test any of the media options with char to determine filter pulsing requirements, filter efficiency, and optimal filter system sizing. ABB CE is developing filter test programs to test filters in actual or simulated gas atmospheres at design temperatures and pressures using steam pulsing for extended periods of time. This testing would establish filter durability, and corrosion, blinding and pinholing resistance with steam pulsing. Adequate test

facilities exist at ABB Corporate Research and the University of North Dakota. Both possibilities are being pursued at this time.

After the second round of char filter proposals, ABB CE engineering was able to produce a physical arrangement of the char filter system, and integrate it into the gasifier island arrangement. This allowed the char filter system to be studied from the viewpoints of interface with the char cyclone and char recycle system, operation, maintenance, and safety. At this point, system availability, system height, system constructability, and system maintainability became major concerns. The emerging nature of hot gas filtration technology and the unavailability of performance guarantees from suppliers made it prudent to build the maximum practical amount of flexibility into the char filter system. For this reason, suppliers were asked to design and estimate smaller multiple filters that could allow on line maintenance, and readily accept a variety of filter media. This resulted in proposals with similar physical arrangements and competitive pricing, while still allowing the different suppliers to incorporate design details specific to their technology. From this data base, ABB CE is currently developing a detailed technical specification for the char filter system that will provide for optimal interface with our gasifier plant, provide operating flexibility, and allow competitive pricing. Test results will be applied to this specification when they become available.

Hot gas filtration technology will continue to be monitored for new developments. Ceramem crossflow ceramic filters and Owens Corning S-Glass filters have recently been studied for this application. The technology for both these materials is not yet as advanced as the ones discussed, but tests are in progress that should determine their suitability for this project.

4.0 DISCUSSION OF SPECIFIC DESIGN ASPECTS

4.1 CHAR FILTER VESSEL CONSTRUCTION

Process operation requires a vessel capable of operation at 294 psia and 1000 degrees f. The physical location of the char filters above the char recycle bins and lockhoppers made vessel height and position relative to the char receiving bin a concern because they are the highest components in the gasifier island and determine roof height. For construction and quality control reasons it is desirable to make these shop fabricated vessels. Shipping considerations then limit vessel diameter to about 12 ft.. These were the major requirements in determining vessel design.

Stainless steel alloys and refractory lined carbon steel vessels were considered for this application. Because the stainless steels had to be designed to operate at 1000 degrees f, their metal wall thickness had to be about twice as thick as the refractory lined carbon steel vessels that could be designed for steel operating temperatures of 400 degrees f or lower. A design study showed the refractory lined carbon steel vessels to be approximately half the weight and cost of stainless steel vessels. ABB CE, Acurex, and Westinghouse each have developed successful technology for refractory lined carbon steel pressure vessels. The refractory linings also offer corrosion protection and better heat retention on start ups. Refractory lined carbon steel was selected for char filter vessel design.

Each filter vessel houses over 100 filter elements. In order to perform filter inspections and maintenance without having to remove all the elements for each operation, a top removal system is required. This design minimizes outage times, and is widely used in the power generation industry. Top removal requires a walk in plenum or a lift off head. Both require about the same amount of height because the heavy lift off head requires space for an overhead crane. The pressure rating of the vessel also requires massive

flanges for a lift off head. A cost study of the two approaches showed that a welded walk in plenum was less expensive than an lift off top with a crane and about the same weight.

The filter hoppers are designed for mass flow. The philosophy followed here is the same as for the coal and char bins, and is described in the "Topical Report for Bins and Lockhoppers". The hoppers cones have very steep angles and smooth walls to promote flow. Although it is not intended to store char in the hoppers, this situation could occur during a system upset or component malfunction in the char recycle system. Several fluidizing nozzles for fluidizing steam are provided on the hoppers for emergency use.

The height of the vessel is determined primarily by hopper angle, vessel diameter, and filter element length. However, the setting elevation of the char filters is determined by the interfaces between the char cyclone and seal bin, char receiving bin, and char filters. It was elected not to use mechanical conveying devices to transport char because of their inherent sealing and cooling problems at the required design temperatures and pressures, and their high cost. Leakage in this area is not just a housekeeping problem, but a safety hazard as well because of the H_2S in the product gas. Conveyance by gravity was elected instead

for its inherent simplicity and safety. This requires the use of downcomers at angles 60 degrees or greater from horizontal. The relationship of the char cyclone and seal bin required the greatest setting height to maintain adequate downcomer angles. Elimination of the char cyclone can result in substantial height savings, and is currently being considered for this and other reasons discussed in section 4.6.

4.2 GAS INLET

The design of the gas inlet to a gas filter is very important to the effective operation of the filter. Major design considerations for gas inlets are: promoting particle drop out, providing even gas and particle distribution to the filters, and preventing direct impingement of the incoming gas and particles on the filter elements. Tangential inlets with shrouds and patented diffuser inlet cones have been offered, and are both being considered. It is not unusual to get 30 to 50% drop out of particulates from a well designed inlet. Drop out at the inlet reduces the load to the filters and reduces the frequency of pulsing. Because the char particles are so fine, credit is not taken for this in the sizing of the filters or the capacity of the pulsing system. Although drop out at the inlet will be significant, it cannot be accurately predicted for char at this time.

4.3 FILTER MEDIA

Many filter media have and are being studied for this application. All the media under consideration are suitable for high temperature operation, but they all have areas of concern that require more testing or actual use to resolve. Except for the sintered metal filters, all the media discussed below are relatively new products that are still in development. ABB CE has requested a one year service life guarantee on filter elements from

all suppliers, but to date has not been able to obtain one. A check of available references for the different filters suggests at this time that it would not be prudent to anticipate a filter service life longer than 3 months. While it is not unusual for conventional bag filters in flue gas service operating at grain loadings of 0.5 grains per acfm to achieve service lives in excess of a year, this is not comparable to gasifier service where the grain loading to the filter elements can range from 280 to 700 grains per acfm of gas. The gasifier service is comparable to flyash conveying service using vacuum systems where conventional bags rarely last a year in intermittent service. These are all reasons that contributed to the decision to require that the char filters be designed to accept several types of filter media, and be capable of being maintained on line. A discussion of the filter media being considered follows:

4.3.1 NEXTEL

Nextel is a continuous polycrystalline metal oxide ceramic fiber that can be woven into seamless tubes for use as a bag type filter element. Nextel fibers and bags are manufactured by 3M Corp. and are being aggressively marketed for hot gas filtration service. Reference I is a paper by 3M that gives more technical background on this material. Nextel can operate at temperatures up to 1100 degrees f with little loss of tensile strength. Because it is a woven cloth, its filtering mechanism is the same as conventional bag filters. The incoming particulates form a cake on the bag that provides a filter barrier even finer than the bag itself. The flexibility of the cloth allows flexing of the bag material when it is pulsed or the gas flow is reversed. The specific Nextel material proposed for this application is number 312 using a 5 harness set and yarns woven of 10 micron filaments. The fabric weight is 16 ounces /sq yd, and the permeability is 15 to 20 cu ft/min-sq ft. Nextel bags are relatively brittle compared to

conventional bag materials. This requires the use of perforated steel tube inserts in lieu of conventional type bag cages. Its brittleness also requires that the bags be handled with extreme care as any creasing will result in pinholes or tears. The clamping of the bags to the cage at each end requires clamping devices that will not lose their grip with fluctuations in thermal expansion.

Nextel has undergone many basic laboratory tests relative to high temperature application and a few simulated use tests. Most notable to date was a test done by 3M in conjunction with the University of North Dakota where nextel bags were installed in a flue gas slipstream from a coal fired stoker boiler that was supplementally injected with coal flyash from pc and afbc plants. The grain loading was light and gas temperatures ranged from 800 to 1000 degrees f. The bags were in service for over 16,000 hours and had a collection efficiency of 99.66 to 99.99%. 3M has also done a laboratory test where a nextel bag was pulsed for 100,000 times using air with no dust loading at atmospheric conditions. The bag showed no significant deterioration at the end of the test. 3M has also tested nextel bags at operating pressure differentials up to 75" of wg in the laboratory with good result.

To date Nextel filter bags are in service in only two commercial installations. In both cases they are used to remove catalyst fines from regenerator flue gas in catalytic crackers at temperatures in the vicinity of 1300 degrees f with very light grain loading. These installations see intermittent service, and have not been closely monitored by 3M. ABB CE is in the process of obtaining a field contact at these installations.

3M's primary concern with nextel bags in the char filter application is what may happen when the bags pass through the dew points for moisture and

acids, or are exposed to condensed steam resulting from steam pulsing malfunctions. Moisture on the bags can cause reactions with the char cake resulting in bag blinding. Of lesser concern is the possibility of strength loss or embrittlement from hydrolysis. From a broader point of view, installation, clamping, and bleeding are concerns. Nextel bags require meticulous installation procedures to avoid creasing or abrasion. Bag clamps that can withstand the thermal cycling of high temperature service are still being developed, and will probably require skillful installation and maintenance techniques. Finally, virtually all cloth type bags eventually bleed (i.e. pass through a percent of small particulates in excess of the bag's rating with no apparent bag damage) or pinhole when subjected to high grain loadings and/or high pressure differentials. The extent that this could be a problem depends on how much carryover the desulfurization system can handle.

Overall the nextel filter bags are suitable filter candidates for the char filters. They have sufficient strength and chemical resistance to be used in high temperature and high pressure service, and both Acurex and Westinghouse who have had considerable experience in this area with a variety of filter materials chose nextel as their first choice for this application at this point in time.

4.3.2 SINTERED METAL

Sintered metal filters made of inconel or hastalloy and manufactured by Memtec America Corp. a division of Fluid Dynamics are being considered for the char filters. The Memtec metal "filter bags" are configured like conventional filter bags. The Memtec metal filter bags are made by a patented process where a nonwoven web of loose random metal fibers is sintered creating a metallurgical bond. The inside bag layer is comprised of relatively coarse fibers that provide a highly porous and strong support

matrix for the very thin and ultrafine outer surface of the bag. The outer surface collects dust cake without allowing penetration of particles into the fiber matrix of the media, but is still permeable to gas. By varying the fiber diameters and the method of web construction, the filter rating can be varied. Removal ratings as fine as 0.3 microns are possible. Reference II gives the manufacturer's address for obtaining commercial information on this product. The metal bags are self supporting and can be supplied with flanged or NPT threaded ends. This feature makes sealing and connection to the tube sheet relatively simple and secure. Perforated metal tube inserts can be provided in the bags allowing the bag to withstand pressure differentials up to 150 psi. Without the inserts, bags are limited to pressure differentials less than 5 psi. This product is commercially available and is in service in a wide variety of applications on both liquids and gases.

Memtec has done considerable laboratory testing on their sintered metal bag filters for many particulates, but never with char or in a reducing atmosphere. More telling are the high temperature applications Memtec inconel bags have and are being used in. Cabot Corp. has been using their inconel bags in a fume silica plant since 1989 with good success. The bags are used to filter very fine (1-2 micron) silica particles from a fluid bed of fume silica. They operate in an oxidizing atmosphere at 1000 degrees f with very heavy grain loading. The filter bags are pulsed cleaned with a mixture of air and nitrogen every 96 seconds. This is a continuous operation. The bags have a service life in this application of about 21 months. However, they must be removed from service and cleaned on a regular basis after the first 6 months of service. Memtec stainless steel bags were also used by ABB Lummus Crest in a maleic-anhydride process to filter catalyst at 482 degrees f, atmospheric pressure, and very light grain loadings. In this application they are pulsed once a shift, and have been in service over a year without requiring any special cleaning.

Sintered metal filters using powdered metal technology manufactured by Pall were tested as hot gas filters in a DOE technology development program to evaluate the use of the KRW fluidized bed gasification process at their Waltz Mill facility near Madison, Pa. in 1985. Two filter metals were tested: 310 stainless steel and inconel 671. The fluid bed gasifier was fueled with bituminous Pittsburgh No. 8 coal for the majority of test runs with dolomite or limestone used as an in bed sorbent in some of the runs. The product gas went from the gasifier into cyclones where most of the solids were removed, and fines were passed on to the metal filter vessel. Gas temperature in the filter vessel ranged from 850 to 1150 degrees f at a nominal pressure of 245 psia with an inlet grain loading averaging 4 grains per actual cu. ft. of gas. The gas contained small concentrations of hydrogen sulfide and carbonyl sulfide. The filters were cleaned by a blowback system that used nitrogen at 500 psia and 250 degrees f. Face velocity was 3.8 ft/min. A water driven venturi was used to remove solids from the bottom of the filter vessel's hopper to a water impounded surge bin located below the filter vessel. Both the stainless steel and inconel filters experienced high pressure differentials anywhere from 24 to 228 hours into a test run. The filters ran longer when in bed sorbent was used for sulfur capture, and worked well until they started blinding. This is all described in DOE report No. DOE/MC/21063-2740, vol 1 & 2, titled "A 50-Month Gasifier Mechanistic Study and Downstream Unit Process Development Program for the Pressurized Ash-Agglomerating Fluidized-Bed Gasification System". This report concluded that the metal filters were blinding due to rapid sulfidation of the filter media that partially destroyed the base metal, and a eutectic of nickel and sulfur that formed in the filter web. As a result, the report determined that metal filters were unsuitable for hot particulate removal in a gasification stream containing significant concentrations of sulfur, but had possibilities for hot gas cleanup following sulfur removal. While the report devoted considerable attention to the metallurgical tests

performed on the blinded filter elements, not much attention was given to the blinding mechanism. Incidents of start up moisture and blowback system failures are mentioned, but their contribution to blinding is not analyzed although either of these circumstances can cause a high pressure differential across any bag filter.

Although sulfidation is certainly a concern with metals containing nickel, ABB CE and Memtec are not convinced that this is an insurmountable problem. The Memtec filter incorporates an outer barrier surface on its metal bag that is much more resistant to blinding than the Pall filters. It is conceivable that the Pall filters blinded due to particle penetration and/or blow back system failure, and then corroded as a result. Memtec is able to offer many exotic metals, including Hastalloy, for their filter construction that have not yet been tested.

Another concern is cost. Metal filters cost approximately twice as much as most ceramic filters per sq ft of filter area. In the case of the char filters, this does not affect the initial capital cost significantly because of the great cost of the pressure vessels. However, the replacement costs could be significantly greater than costs for ceramic filters.

Memtec metal filters still have great appeal in spite of these concerns because of their durability and strength. Their attachment to the tube sheet is the least problematic of all the filter options, and installation does not require a high level of special handling. Mikropul continues to prefer Memtec metal filters over the other options.

4.3.3 CERAMIC CANDLE AND TUBE FILTERS

Rigid ceramic candles and tube filters are both ceramic tubes with porous

walls that can be constructed of a variety of ceramic materials including: alumina/mullite, cordierite, aluminosilicate, and silicon carbide. All these materials are suitable for and being developed for coal based process gas temperatures in excess of 1200 degrees f. Candle filters receive dirty gas on their outside diameters and are suspended from a tube sheet similar to a typical bagfilter configuration. Tube filters receive dirty gas on their inside diameters, and are supported by a tube sheet on both ends. This has a structural advantage over candles, but it may be offset by the limited allowable build up of solids in the tube in applications of high grain loading. The tube filter is currently being developed by Asahi Glass Co., Ltd. Rigid ceramic filters cannot flex and require somewhat higher pulse pressures and longer pulse durations than cloth type filters for cleaning. Cake formation is also more difficult on rigid ceramics. The advantages of this are that pore size is constant and that very fine pore sizes can be achieved with good permeability resulting in ultra high filter efficiencies. Reference III is an article from "Chemical Engineering Progress" that gives a current overview of ceramic filters for hot gas filtration.

In 1991 when ceramic filters were first investigated by ABB CE, these type of filters were just beginning to be tested. Initially there were problems with the binders that held together the ceramic matrix particularly in the presence of steam. Also, in the case of candles, there were structural failures where the candles were connected to the tube sheet. Since then, many of these initial problems have been resolved although the tube sheet interface and vibration continues to be troublesome. To date ABB CE has been unable to find a reliable rigid ceramic filter design. On the second round of inquiries to the filter suppliers mentioned earlier, none would recommend using ceramic candles for our application unless we specifically requested them. Gas temperatures in excess of 1200 degrees f are common to hot gas filter applications for pressurized fluidized bed,

incineration, and catalytic recovery, and this is primarily where they are being developed for. The ABB gasifier process does not require gas temperatures into the char filter in excess of 1100 degrees f, and is available to less exotic filter materials. The development of rigid ceramic filters will continue to be monitored, but at this time they are considered the option of last resort.

4.3.4 CERAMEM FILTERS

Recently, ABB CE began to investigate Ceramem ceramic crossflow filters as a possible future candidate for char filtration. The Ceramem filter technology is highly proprietary and very promising, but not yet fully developed or proven for most commercial applications. Ceramem filter media has the following advantages over conventional media and ceramic candle filters:

- High temperature operation up to 1800°F.
- Very low coefficient of thermal expansion of 1×10^{-6} in/in/C
- Extremely large filter area per unit volume.
- Very high filtration efficiencies with particles smaller than 1 micron

There are, however, serious concerns about how to clean this media and how to arrange it. Ceramem's first large scale long term test as a flue gas filter on a conventional coal burning power station is underway at Public Service of Colorado's Comanche Station where these issues will be addressed for the first time for conventional power plant uses. ABB CE is studying how Ceramen could be used for hot gas filtration on the Springfield Repowering Project. Based on operating criteria given to us by Ceramem for backpulsing frequency, it appears that this media is not feasible unless testing can demonstrate that the need to backpulse the media is not as frequent as anticipated, or the basic structural configuration of the Ceramen

is altered to allow cake formation. The latter would eliminate the filter area per unit volume advantage, but may still yield a superior hot gas filter. If the cleaning requirements for Ceramem prove to be less than anticipated for high char loading, preliminary calculations show that a Ceramem char filter could be approximately half the size and cost of char filters designed with the filter media discussed above. ABB's Corporate Research Group plans to test Ceramem filter media in their new High Temperature High Pressure (HTHP) Filter test rig in Baden, Switzerland in the fall of 1993. An IGCC application will be considered in developing the test parameters.

Appendix III shows the basic configuration and concept for Ceramem, and a current list of field tests. Cell structure can be obtained in round or triangular shapes and different densities. At this time, Ceramem is producing only three honeycomb type filters in two cell sizes:

FILTER SIZE	FILTRATION AREA	
	2mmX2mm	4mmX4mm
5.66"dia X 6"long	10 sq ft	5 sq ft
5.66"dia X 12"long	21 sq ft	10.5 sq ft
5.9"square X 12"long	37 sq ft	18.5 sq ft

The ceramic honeycomb structures are extrusions of cordierite supplied by Corning. Cordierite is a ceramic made up of silica, alumina, and magnesia (2MgO , $2\text{Al}_2\text{O}_3$, 5SiO_2) and is comparable to mullite in strength and corrosion tolerance at high temperatures. Ceramem Separations L.P. has developed the technology for applying thin ceramic membrane coatings to the honeycomb monoliths. The membrane coatings have pore sizes substantially smaller than the pore size of the monolith material and function as surface filters. Pore sizes of the membrane coatings range from 0.5 to 0.004 micron. The monoliths are filled with a liquid medium containing a mixture of ceramic powders, dispersant, and polymeric binders that are absorbed into and onto the walls of the monolith. The coated monolith is then dried and fired to bond the ceramic membrane particles. Membrane pore size and porosity are determined by the particle size of the ceramic powders used in the medium or "slip". Cell passage ways are plugged with a ceramic cement on each end of the monolith in a manner to cause the gas to have to flow through the cell walls to exit the filter. The Ceramem modules can be held in place by casting them into place in metal housings using ceramic fiber mats and cements. There is much flexibility in this approach, and it does not require the type of troublesome tube sheet connection as used with candles.

To date, field tests of Ceramem filters for particulate removal have been conducted at fourteen sites with supporting tests at Ceramem. The duration of tests ranged from 48 to 1100 hours at gas flow rates from 20 to 600 ACFM. Appendix III lists the tests completed as of February 1993. The most impressive result of all these tests is that the honeycomb cells have not plugged even with sticky particulates, and

that cleaning requirements have been the same or less than conventional filters in the same service. The mechanism for this positive performance is not entirely understood at this point. One important consequence of Ceramem's resistance to blinding and cake formation is that particulates tend to disperse as a cloud when backpulsed and quickly re-entrain into the dirty gas stream. Getting very fine particulates to drop out of the gas stream in this operating mode is a major focus in the development of Ceramen filters at this time.

4.4 TUBE SHEET

Design of the tube sheet is of critical importance to the successful operation of the char filters. Thermal expansion, the ability to withstand high pressure differentials, corrosion, and filter element connection are the major design considerations for this component. The tube sheet will experience differential rates of expansion with the filter housing due primarily to their different operating temperatures and materials of construction. The tube sheet will be constructed of a corrosion resistant stainless steel alloy and will be directly exposed to the product gas. It will be seal welded to the housing, and incorporate a leaf spring in its outer diameter to accommodate expansion differentials. The resulting structure of the tube sheet coupled with the leaf spring also minimizes the effects of thermal creep and cycling fatigue. Filter element attachment will allow for top removal of the elements, the insertion of Nextel, sintered metal, or ceramic candle type elements, and gas tight sealing of the elements to the tube sheet. Several proprietary attachment details are being evaluated for this purpose.

4.5 CLEANING SYSTEM

4.5.1 CLEANING METHODS

Three types of cleaning systems were considered for the char filters: mechanical, reverse gas, and pulse jet. The pulse jet concept is the most flexible and feasible of the three, and is the selected method of cleaning the char filter.

Mechanical shaker systems were the original type of cleaning mechanism used to clean conventional bag filters. Both mechanical shaker and reverse gas cleaning systems in conventional bag filters collect solids on the inner diameter of the bags, and require that the filter be isolated from the dirty gas flow while being cleaned. The allowable volume available for cake build up is significantly less than when the cake is allowed to build up on the outside of the bags, and therefore mechanical and reverse gas cleaning systems usually require a low (1:1) gas to filter area ratio. The greater amount of time mechanical and reverse gas systems require to clean is also a factor in determining this ratio. In both of these types of systems the bottom of the bag is held in a tube sheet and the top of the bag is suspended on a spring to allow collapse of the bag to promote shedding of the cake. This arrangement does not lend itself to a high temperature high pressure application because it cannot tolerate pressure differential greater than 8 inches wg, and springs do not function well or last long in high temperatures. The low gas to filter area ratio also requires larger or more char filters than a pulse system.

It may, however, be possible to use a modified mechanical or reverse gas cleaning on arrangement where the filter elements are suspended from

the tube sheet and solids are collected and filtered on the outside diameter of the filter elements just as they are in a jet pulse system. The major difference would be that gas flow through the filter would have to be stopped or reversed during the cleaning operation. Although this arrangement is workable, there are several concerns.

The isolation valves required to control gas flow through the char filters during the cleaning period have to be very similar to the specialized and very expensive ball valves being considered for use in the coal and char lockhopper systems. The cost and availability of these valves in sizes over 12" in diameter is very prohibitive. Although the use of 12" valves is possible, there can be a penalty in pressure drop and/or the number of char filters required to reduce the volume of gas through the valves to permit smaller diameters at reasonable gas velocities. The isolation valves would have to be actuated on the order of every 5 to 10 minutes to permit a cleaning cycle at a gas to filter area ratio of 1:1. While such an operation is possible, it would be very maintenance intensive and would require four 50% char filters as a minimum in order to stay under a 12 ft vessel diameter. This type of arrangement would not become feasible unless a filter design can be developed that allows the char filter to operate at least one hour without cleaning at gas to filter area ratios greater than 1.5:1.

In the case of reverse gas, another concern is the effect of the reverse gas on the gasification process. The reverse gas has to either be backwashed into the product gas stream going to the filters operating in the collecting mode, or vented to atmosphere. The latter is unacceptable, and the former causes dilution and/or momentary disruptions in product gas volume.

Mechanical systems have the additional problem of operating mechanical linkages and vessel penetrations in a high temperature high pressure environment. Suppliers were asked to look at using hydraulically or steam actuated vibrators as a possible cleaning alternative that would require no cleaning media and very little power consumption. This has never been attempted, and would require significant development work. Because of this and anticipated problems with the tube sheet, this option was not pursued beyond the conceptual point.

Pulse jet cleaning systems have been used successfully on conventional and high temperature high pressure gas filter systems with all of the filter media discussed in this report. Pulse jet cleaning systems discharge a short blast of cleaning gas into a portion of the filter occurs without having to halt or reverse from the clean side of the filter element to remove particles on the dirty side of the filter. The cleaning gas must be supplied at a pressure greater than the operating pressure of the char filter, and only a portion of filter elements are pulsed simultaneously to allow continuous filter operation. On cloth type filters this action also flexes the bag. Depending on the char loading to the char filters, gas to filter area ratios of up to 3:1 are feasible.

Pulse duration, frequency, and pressure are dictated by solids loading, solids permeability, and the type of filter and cleaning media. High solids loading and/or low solids permeability require more frequent pulsing for a given filter size. Rigid filters with small pore sizes generally require higher pulse gas pressures and longer pulse durations to achieve effective cleaning. Lower density cleaning media require more volume than higher density media. This can be controlled by pulse valve sizing as well a pulse duration and pressure.

4.5.2 CLEANING MEDIA

Superheated steam, nitrogen, and clean product gas were all considered for use as the cleaning media in the jet pulse arrangement. All are acceptable gases for this service, but steam was selected for its economics and relative simplicity.

Estimates for the use of nitrogen to pulse the char filter arrangement used in the cost estimate are in the range of 1800 to 3600 lbs/hr. This is significant usage in a gasifier process that is not oxygen blown with a ready source of nitrogen. Nitrogen for pulsing would have to be supplied by increasing the capacity of the nitrogen supply system for the coal feed system and adding a booster compressor. This increases the capital and operating costs of the coal feed system and further compromises one of the advantages of using an air entrained gasifier. Even so, nitrogen would provide the most trouble free pulsing system operation due to its inherent dryness and inertness. All of the char filter suppliers preferred nitrogen a cleaning media.

In order to use product gas for pulsing, clean desulfurized product gas would have to be extracted upstream of the gas turbine and be cooled from 1000 to 250 degrees f and than compressed to at least 1000 psig. Material temperature limitations in the compressor limit outlet temperatures to around 450 degrees f. The addition of a heat exchanger and booster compressor add cost and complexity to the gasifier system. This system does have the advantage, however, of not diluting the product gas.

The primary and very real concern with the use of superheated steam for pulsing the char filters is condensation. Superheated steam has the advantages of being readily available from the process at high temperatures and pressures (up to 1500 psia at 1000 degrees f), and comparatively inexpensive, but it must remain dry to provide acceptable service. Even small steam leaks can produce moisture as can cold internal surfaces during start ups and shut downs. Moisture on the filter elements can cause blinding and corrosion, and in the filter hopper can cause hideout and hopper pluggage. Design provisions and operating precautions must be taken to prevent these circumstances from occurring. These include steam leak detection systems and heating of the vessel on start ups and shut downs. Although the use of steam as a pulsing media is rare in conventional bag filters, it has been used successfully. Cabot Corp. has been using a steam pulsed bag filter to filter a reactor gas with a high moisture and sulfur trioxide content since 1950. The filter bags are Nomex and the operating gas temperature is 425 degrees f. Average bag life ranges from 6 to 9 months. Cabot reports that the bag filter operates the best when it is run continuously at high temperature.

4.5.3 PULSING VALVES

The design of the pulsing system components for the char filters is relatively straight forward and similar to conventional bag filter technology except for the pulsing valves. In conventional jet pulse bag filters, the pulse valves are normally off the shelf solenoid valves operating with compressed air at pressures below 100 psig and temperatures less than 350 degrees f. Solenoid valves are the preferred valves for jet pulse service because they are very fast acting and can deliver a square type pressure wave when time is plotted against pressure. This type of pressure pulse is the most effective for bag cleaning, and is also desirable for the char filter

application. The valve size required for steam pulsing is about 2" i.d. Available solenoid valves for high temperature steam service are limited to temperatures of 750 degrees f and 2500 psig. The char filter service will require each pulse valve to cycle about 100,000 times when operated at full load for a year. High cycles, high pressure drop, and high steam temperatures put these valves at the limit of their capability. It is anticipated that the valves will require a major rebuild or replacement every 50,000 cycles. High local ambient temperatures may require that the solenoid coils be provided with a cooling system. In order to ensure availability of this system, redundant pulse valves will be installed to allow on line replacement. A system will be provided to detect a failed pulse valve and automatically switch to the installed spare. To date this area has not received the intense scrutiny that filter materials have although the performance of the pulsing system is critical to the successful operation of the char filter. In the future, it is planned to investigate the use of fast acting ball valves as an alternative to solenoid valves.

4.6 SOLIDS LOADING

It was mentioned earlier in this report that eliminating the cyclone upstream of the char filters is being considered in part to reduce char filter setting height. Because fifty percent of the char particles are very small, most of this fraction will carry through the cyclone into the char filters. Uniformly small particles are the most difficult solids to filter. In the case of the nextel, they can penetrate pore openings, and in all cases they resist the agglomeration and cake formation that are essential to efficient filtration. All the char filter suppliers agreed that it would be advantageous from this viewpoint to eliminate the cyclone and let the entire range of particle sizes and shapes into the char filters to promote better filtration and easier particle drop out. The only drawback to this premise is that the already

high solids loading to the char filters goes even higher. The result of this, is that the pulsing frequency must be increased and/or gas to filter area ratio must be reduced. Because the pulsing requirements for this particular char are not known, estimates have been made by the filter suppliers based on limited existing char data. In order to keep pulsing frequencies greater than every 3 minutes with the case of low permeability char, it is necessary to reduce gas to filter area ratios to 1.5:1. This requires going from two 12 ft diameter char filters to four 10 ft diameter char filters. At first glance this seemed more costly and more cumbersome to the gasifier arrangement. It turned out, however that this arrangement permitted a 20 ft reduction in setting height without requiring any additional bays, and the cost difference between two big filters versus four smaller filters was insignificant. Apparently, the small cost difference is possible because major components to the char filter cost are design, contingency, and set up for fabrication. Two additional benefits are greater operating flexibility for doing on line filter repair, and the ability to use smaller char filter isolation valves.

4.7 OPERATING TEMPERATURE

As discussed earlier, the zinc titanate desulfurization system requires gas temperature in the area of 1000 degrees f to be effective. Other types of desulfurization systems such as zinc ferrite or iron oxide would allow char filter operating temperatures in the areas of 800 and 600 degrees f respectively. Temperatures in this range would allow the use of fiberglass filter bags like S-glass from Owens Corning, but would still be out of the range of nomex and other conventional filter media. Our investigation of fiberglass bags is just beginning, and it is not known at this time if they would bring any advantage over nextel. The only clear advantage to lower temperature operation would be the ability to go from ANSI class 600 isolation valves to class 300 in both the char filter system and the char

recycle system. It would also be possible to use carbon steel vessels with no refractory lining, but it would still be desirable to keep the lining even at these temperatures. In any case, the cost savings would be small if the refractory is eliminated.

4.8 HOPPER HEATING

Heating of the char filter hoppers will be provided through the use of steam coil heaters or steam tracing. These heating devices will be used to prevent hopper surfaces from getting cold enough during start ups or shut downs to allow condensation of moisture out of the product gas. The other portions of the char filters will not require heating devices. They will achieve sufficient temperature from the flue gas generated by the gas burners during the lengthy gasifier start up periods.

4.9 CONTROLS

The char filters will incorporate the following instrumentation: high hopper level switch, differential pressure transmitter, and "broken bag detector." Initially, it is planned to trigger pulsing by differential pressure signals with a timer system as a back up in the distributed control system. A high hopper level will alarm in the control room and automatically initiate operation of steam nozzles at the hopper outlet. The broken bag detector will sense excessive carryover of particles at the outlet of each char filter. This condition will alarm and automatically isolate its associated filter for maintenance.

4.10 COST

When the cost of the char system described in this report is compared to the cost of a baghouse for a conventional pulverized coal bagfilter for a 60 mw plant, the char filter system is 4 to 7 times greater depending on the specific requirements of the conventional coal plant. Even though the char filter system is much smaller due to its greater operating pressure, this does not overcome the extra costs for pressure vessel construction and new technology. It is expected that the cost differential would go close to zero as the plant size is increased and standard designs for hot gas high pressure filters are developed.

5.0 FUTURE WORK

ABB CE will continue to monitor developments in hot gas filtration media. A detailed technical specification for procurement of the char filters will be developed that stipulates the design features discussed in this report. This specification will put all the bidders on the same basis and ensure the project of competitive bids and a workable char filter system.

ABB CE will continue to pursue a test program to develop the following design data for the filter media discussed in this report:

- Filter pressure drop and efficiency for gasifier char at high temperature and pressure.
- The effects of corrosive gas on the filter in a reducing atmosphere.
- The effects of using steam to pulse clean the filter.
- An estimate of filter life in the intended service.

ABB's Corporate Research Group has assembled a high temperature high

pressure test facility in Baden, Switzerland for measuring the performance of hot gas filtration media. This facility will start up in June of 1993 and could be available for our purposes in early 1994. Appendix IV shows the test rig configuration and lists its capabilities. Another opportunity available to ABB is the new transport reactor facility at the University of North Dakota. This facility can generate a product gas and char similar to our gasifier process by reacting Illinois no. 5 coal. A filter housing exists that could accommodate the filter media to be tested. This facility could be available for our purposes in the fall of 1993. Test program definitions are being formulated, and we are reviewing these to determine ABB CE participation levels. Regardless of whether either of these tests take place, 3M Corp. will test Nextel at the U.N.D. facility at high temperature and pressure, and Memtec will do some bench scale corrosion tests on a variety of sintered metal media to determine the effects of H₂S exposure on their particular filter structure.

All the suppliers of filter media are capable of doing basic filter efficiency and pressure drop tests with this material at no charge. At this time only 3M Corp. has signed the confidentiality documents necessary to use the char sample. The paperwork to allow Memtec, Ceramem, Acurex, Westinghouse, and Mikropul access to this sample is being processed.

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