Application of a Barrier Filter at a High Purity Synthetic Graphite Plant CRADA 99-F035, Final Report

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1.0 INTRODUCTION

Superior Graphite Company and the U.S. Department of Energy have entered into a Cooperative Research and Development Agreement (CRADA) to study the application of ceramic barrier filters at its Hopkinsville, Kentucky graphite plant. Superior Graphite Company is a worldwide leader in the application of advanced thermal processing technology to produce high purity graphite and carbons. The objective of the CRADA is to determine the technical and economic feasibility of incorporating the use of high-temperature filters to improve the performance of the offgas treatment system. A conceptual design was developed incorporating the ceramic filters into the offgas treatment system to be used for the development of a capital cost estimate and economic feasibility assessment of this technology for improving particulate removal. This CRADA is a joint effort of Superior Graphite Company, Parsons Infrastructure and Technology Group, and the National Energy Technology Laboratory (NETL) of the U.S. Department of Energy (DOE).

The Superior Graphite plant, located in Hopkinsville, Kentucky, produces high purity synthetic graphite by removing sulfur and other constituents from calcined petroleum coke in high-temperature electric induction furnaces. Operating at temperatures exceeding 2760 °C (5000 °F), this process converts amorphous carbon to graphite and generates a flue gas containing N₂, CO, H₂S, and other sulfur compounds, along with particulate matter emissions. Gases exit the furnaces at temperatures on the order of 1980 °C (3600 °F). The Hopkinsville plant has multiple furnaces, each with an afterburner. The gases are cooled in a gas cooler by dilution air to 250 to 325 °C (480 to 620 °F). Then the gases are manifolded to a single multiclone dust collector and subsequently sent to a dual alkali sulfur dioxide scrubber system. In addition to the SO₂ absorption tower, the scrubber contains multiple mist eliminators and multiple rotary atomizers, which are also equipped with downstream mist eliminators. The latter are for fine particulate control and mist suppression geared toward minimizing stack opacity. Efforts are underway to improve both particulate emissions and opacity, which is the focus of this evaluation.

The particulate matter coming from the furnaces consists of coke dust and ash. The use of a high-temperature filter downstream of the afterburner but upstream of the scrubber to remove coke dust and ash could provide several benefits including:

- Removal of the particulates going to the scrubber.
- Reduction of particulates entrained in the scrubber tower and dissolved solids in the scrubber mist.

To better define the technical issues and the costs versus benefits of this option, conceptual designs and cost estimates of the use of a barrier filter in this application were performed.

2.0 APPROACH

The following tasks were completed during the course of this agreement:

- **Confidentiality Agreement** – A confidentiality agreement was developed and executed between Superior Graphite and Parsons Infrastructure and Technology Group.
- **Plant Information Sheets** – Parsons developed and submitted to Superior Graphite a request for information sheet. The information request sheet queried Superior Graphite on the plant operating and design parameters. General areas of interest included local environmental conditions, process operating range (temperature, pressure, and flow rates), expected filter design conditions, flue gas composition, and particulate morphology. Information not available was estimated in consultation with Superior Graphite.
- **Site Visit** – A site visit was conducted to tour the Superior Graphite facility located in Hopkinsville, Kentucky. At that time discussions were held to identify technical issues that must be addressed, to finalize the conceptual design basis, and to agree upon the costing scope.
- **Site-Specific Conceptual Design** – Parsons developed site-specific conceptual designs for the Hopkinsville, Kentucky plant. The conceptual designs were generated to illustrate how a barrier filter system could be integrated into this Superior Graphite plant. The designs conceptually addressed technical issues identified at the site visit. The conceptual designs included a system diagram, system and component descriptions, and a general arrangement drawing. Vendor input was solicited for major equipment.
- **Cost Estimate** – Parsons produced a capital cost estimate based on the system scope as described in the conceptual design. The estimate was based on equipment quotes and in-house cost data. Parsons also identified the operating and maintenance (O&M) requirements.
- **Engineering Report** – An engineering report was developed by Parsons to present the conceptual design, capital cost estimate, and an assessment and description of the technical issues as they apply to the Hopkinsville plant.

3.0 BARRIER FILTER APPLICATIONS

Development of hot gas cleanup technologies has tended toward producing a barrier type filter, capable of meeting the ever-decreasing limits for particulate emissions, that is free from the restriction of temperature excursion vulnerability. Conventional technologies are limited to operating temperatures lower than 260 to 315 °C (500 to 600 °F). Filtration at higher temperatures can offer several advantages including:

- Elimination of the need for gas cooling or gas dilution equipment.
- Reduction of maintenance by avoiding dew point corrosion problems.
- Increasing efficiency by recovering additional energy or valuable byproducts.

Twenty years ago hot gas barrier filters were almost unknown, with the exception of a few specialized applications. Barrier filters are now commercially available for moderate temperature and pressure (less than 1000 °F and 1 atm) applications with the availability of several products in the U.S. and Europe market and the practical application in numerous industrial sectors.¹ The market barriers of cost and reliability have prevented widespread applications of these filters. However, these barriers should begin to fade as the filters are more widely accepted in the marketplace due to more stringent emission regulations being placed on the user.

The DOE's involvement with high-temperature, high-pressure particulate removal started in 1978, primarily for pressurized fluidized bed combustion (PFBC) and integrated gasification combined cycle (IGCC) applications. These were at higher temperature (1200 to 1500 °F) and pressure (10 to 25 atm) than most industrial applications. At least 10 devices were tested at a bench scale under simulated PFBC conditions. In 1982 two devices, a ceramic felt bag filter and an electrostatic precipitator (ESP), were installed at the Curtiss-Wright PFBC pilot plant and tested at actual PFBC conditions. In 1986 a granular bed filter, a redesigned ESP, and a ceramic cross-flow filter were tested at the New York University PFBC pilot plant.

In Europe, silicon carbide candles were being tested in England at Grimethorpe's PFBC and at other test facilities in Germany and Finland. By 1989, the candle filter appeared to have the best chance for success in both PFBC and IGCC environments. A demonstration-scale test of a candle filter was done at the Tidd PFBC plant. Results of the final series of tests were positive, although long-term testing above 815 °C (1500 °F) was still needed. Other devices such as cross-flow filters, ceramic tube filters, and granular bed filters continue to be developed, but will need much more testing at pilot and demonstration plant scale before acceptance is attained.

Presently, the DOE is sponsoring a coordinated program to commercialize hot gas particulate collection technology. This program includes research and development, slipstream testing, and pilot plant testing at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama, and clean coal technology demonstration plants.²

3.1 TYPES OF BARRIER FILTERS

The most common form of barrier filters is referred to as a "candle," closed at one end and open at the other.³ Candle filters are typically suspended from a tube sheet, which may be made from high-temperature metal, or from ceramic in the case of the lighter weight ceramic filters. Each tubesheet holds an array of individual candles, and tubesheets may be grouped horizontally and vertically. Tubesheets may be solid, or hollow for water-cooling. The filters are closed or sealed on one end and flanged on the other end for mounting on the tube sheet. Dirty gas impinges on the outer surface of the candle and clean gas is carried away down the hollow center of the candle. The particulates are captured on the outer face of the candle and cleaned off with pulses of compressed air directed down the center of the candle, much as in a reverse pulse jet filter. Captured particulates then fall down from the filters and are collected in a hopper.

The main difference between ceramic media and conventional fabrics results from the ceramic nature of the material. This gives the filter the capability of operating at sustained high temperatures and in corrosive atmospheres. The media are unaffected by sparks and can even withstand combustion of the collected solids on the surface of the filter elements for short periods of time. Acid or alkali materials have little or no effect on the materials.⁴

As with fabric filters, the bulk of the filtration is achieved by the buildup of a porous cake of particulates on the surface of the filter, which prevents further penetration of the media. In some situations, this barrier of dust is artificially added (pre-conditioning) to improve the filter's performance. This barrier, or conditioned, layer of particulate matter gives an increase in pressure drop over the original media. However, it also gives rise to excellent filtration efficiencies. Because this conditioned layer is permanent, the rigid ceramic elements do not clean down completely when pulse cleaned as fabric filters do. This results in virtually no penetration of the filter and can result in less than 5 ppm of particulates in the emissions (approximately equivalent to 0.0025 grs/scf).⁵

For a given application, the filtration velocity can be higher than that used for fabric filters, as the ceramic filter is permanently protected from dust penetration by the conditioned layer. With a fabric filter, pulse cleaning periodically strips away the protective layer, allowing particulate penetration of the media.

The combination of the filter's temperature resistance and its ability to withstand surges in volume means that barrier filters are less likely to be susceptible to damage caused by variable conditions and process upsets.

Ceramic monolithic candle filters were the first type of candle filters to be designed, manufactured, and tested in the hot gas cleanup program for coal gasification and PFBC gases. The three companies that provided these candle filters were:

- Refractron – Clay-Bonded Silicon Carbide: Silicon carbide grains held together with a clay-based binder (Pall Corporation currently has a marketing license agreement with Refractron for sales of ceramic candle filters).

- Coors – Alumina Mullite: A monolithic oxide ceramic, made up of mullite, anorthite, and alumina.
- Schumacher – Clay-Bonded Silicon Carbide: Silicon carbide grains held together with a clay-based binder.

Ceramic fiber candle filters have been developed to provide materials that are more flexible than monolithic ceramics and do not fail in a brittle manner but are not as strong and are more susceptible to thermal shock. The composite material will not creep or be degraded by exposure to a hot gas cleanup environment.⁶ The filter suppliers for these materials are:

- 3M – CVI Silicon Carbide – Nextel Continuous Fiber Composite: Nextel (aluminosilicate) fibers with CVI silicon carbide coating. A carbon interface coating is used. Chopped fibers bonded with CVI SiC make up the filtration layer, which is held in place with an over wrap of CVI-coated fibers. This type was tested at PFBC conditions. Second-generation candle filters made of 3M CVI-SiC composite have also undergone testing at one of the Westinghouse hot gas filtration systems in Pittsburgh.
- B&W – Continuous Fiber Ceramic Composite: Filament-wound alumina-based fiber, infiltrated with chopped fibers, which form the filtration surface. A program to develop a filament-wound alumina-based filter with a coating matrix of chopped ceramic fiber (Saffil) was initiated. Mitsui's ALMAX alumina fiber and 3M's NEXTEL 610 alumina fiber were used as the basis for the filters.
- DuPont – Lanxide PRD-66: An oxide ceramic material derived from wound fibers containing alumina, mullite, cordierite, and a glass phase. The microstructure is microcracked. A version of this type was tested at Tidd. Second-generation candle filters made of DuPont PRD-66 were developed and tested at one of the Westinghouse PFBC hot gas filtration systems in Pittsburgh.
- DuPont – Lanxide Silicon Carbide Composite: Silicon carbide fibers coated with CVI silicon carbide. A fiber interface coating is used, which is probably carbon. Chopped fibers make up the filtration surface. Second-generation candle filters made of DuPont SiC-SiC were tested at one of the Westinghouse PFBC hot gas filtration systems in Pittsburgh.
- Textron – Continuous Fiber Ceramic Composite: Filament-wound, Textron SCS-6 SiC fiber, nitride bonded silicon carbide composite. SCS-6 fiber surface provides appropriate mechanical properties. Difficulty in maintaining porosity and strength raised questions concerning the usefulness of this formulation.
- Westinghouse/Techniweave/3M – 3-D woven NextelTM (aluminosilicate) fiber infiltrated with mullite using a sol gel process. A program to develop and test a fiber architecture and a fabrication process for a Nextel 550 based fiber-reinforced ceramic composite material was completed.

- **Industrial Filter & Pump Fibrosics** – Vacuum-formed chopped aluminosilicate fibers, having light weight and low strength. IF&P has developed a lightweight modified aluminosilicate material (Fibrosic) that can be used for candles and other parts of the filter structure, such as tubesheets. Since the candles are much lighter than monolithic ceramic candles, the tubesheet can support candles made of Fibrosic but not of the heavier ceramics. IF&P has developed a silicon carbide candle filter material that is stronger and can withstand higher thermal shock levels than the presently available aluminosilicate material.
- **BWF America, Inc.** – Alumina silicate fiber, or argillaceous earth silicate fiber ceramics. Alumina silicate fiber ceramic filter elements were designed and tested in power plant conditions (i.e., at low pressure) on three plants at temperatures of 650 to 920 °C (1200 °F to 1690 °F) for up to 2,600 hours. The elements have also been tested on filtering other types of materials with similar results.

While work has centered on the development of candle filters, there is still interest in other devices such as ceramic tube filters, cross-flow filters, and sintered metal filters. Table 3-1 is an overview of developers and products.³ Not all of the system suppliers manufacture the filter elements used in their filter systems, and several manufacturers furnish only the filter elements.

Table 3-1
Overview of Particulate Control Device Developers

	Ceramic Candle System	Ceramic Candle Element	Ceramic Fiber Candle	Ceramic Tube	Ceramic Cross- Flow	Sintered Metal	Cross- Flow System
Westinghouse	X		X				
USF/ Schumacher	X	X					
Pall	X					X	
IF&P	X		X				
LLB	X						
Refractron ^a		X					
Coors		X			X		
3M			X				
B&W			X	X			
Lanxide			X				
Textron			X				
BFW			X				
Asahi				X			
Blasch					X		
CeraFilter					X		X

^aRefractron is the sole supplier to Pall.

- **Asahi Glass Co., Japan** – The tube filter is typically made of porous cordierite. The tube elements are butted together to form 20-foot vertical units, and 9 to 85 of these units can be housed in a pressure vessel. The tube differs from a candle filter in that it requires mounting fixtures on both ends where they are butted together. There are tube sheets at the top and bottom of the butted tubes. Furthermore, in operation, the dirty gas enters at the top, then

flows downward inside the tube at high velocity. Clean gas exits horizontally and outside the vessel through side outlets. A reverse pulse through the clean exit pipes using a venturi effect blows the Asahi tube filters back.

Ceramic cross-flow filters were developed to provide a hot gas cleanup device that could perform the same function as a candle filter, but in a smaller piece of equipment. The filter is made up of layers of porous ceramic laid in strips to create passageways. The gas inlet side strips are laid at 90° to the gas outlet strips so that gas flows have to pass through a ceramic membrane to exit. By arranging the gas passageways in this manner, the utilization of space available is maximized.

- Westinghouse: Composed of alumina/mullite ceramic materials provided by Coors. Sheets and channels are placed in alternate layers at 90° orientation in stacks and fired to produce a monolithic ceramic structure. Problems with delamination of the ceramic strips have slowed the development of this type of filter by Westinghouse.
- Blasch: Owns a proprietary injection molding process, which can be used to fabricate a monolithic cross-flow filter. This filter is similar in design and function as the Coors cross-flow filter manufactured for Westinghouse by Coors.
- CeraFilter: Similar to a cross-flow filter, the CeraFilter Ceramic Monolith Filter is a porous honeycomb monolith made from a Corning ceramic body and EX-80 cordierite material coated with a fine particle filtration layer. CeraFilter Systems is a joint venture between CeraMem Separations, Inc. and Foster Wheeler Energy International, Inc., formed in 1994 to use the background of both companies to develop hot gas cleaning systems for coal and biomass conversion processes.

Pall Corporation has developed metallic filters for high-temperature application. The two materials utilized are:

- Iron aluminide: Sintered metal iron aluminide. Alloy is resistant to corrosion by sulfur compounds.
- Stainless steels: Sintered stainless steel for application in IGCC downstream of a desulfurization system. Stainless filters were tested at the Waltz Mill gasifier. At an operating temperature of 675 °C (1250 °F) and with 600 to 3,000 ppm sulfur, the filters failed. When tested with less than 30 ppm sulfur in the gas stream, the filters performed satisfactorily.

3.2 FUNDAMENTAL AND DESIGN ISSUES

The fundamentals of particulate removal from gas streams have been studied, and equations have been formulated to predict filter performance.³ Above 500 °C (932 °F) there is less information; however, theoretically, the filters should perform similarly at high temperatures and pressures since they employ the same particle capture mechanisms. The capture mechanisms involved are:

- Interception

- Diffusion
- Inertial impaction
- Gravitational settling

The most important physical characteristics of the particle relating to these capture mechanisms are density and diameter. Removing particulate from a high-temperature, high-pressure gas stream for physical characterization is difficult, but techniques have been developed to collect representative, isokinetic samples from these environments. In situ analysis is being developed using laser spark spectroscopy and Fourier transform infrared spectroscopy, providing another analysis technique. Real-time measurements will provide histories of alkali and particulate concentrations. However, it must be emphasized that many fundamental process parameters are not yet commonly available nor easily estimated by theoretical means.

There are two possible complications that can affect system performance for which no analytical mechanism exists: re-entrainment during blowback of barrier filters and penetration of particles due to bypassing, cracks, or construction defects.

After the particles are collected on barrier filters, they must be blown off and separated. In order for this to occur, the blowback pressure must be sufficient to stop the forward filtration of the dirty gas and exceed the cohesive force among the particles and the adhesive force between the particle or cake and the filter medium. This force is called "separation stress" and is a complex function of material, temperature, pressure, and the manner in which the particle is deposited. A fair amount of modeling and research has been done concerning separation of particles from barrier filters. The purpose of this modeling work was to find ways to reduce harmful effects of blowback on the ceramic filters.

3.2.1 Pressure Drop Considerations

The total pressure drop for a barrier filter consists of the following:

- The clean element pressure drop including the clean gas ductwork, which is a function of gas flow, density, and viscosity.
- The residue pressure drop, which is a result of "conditioning" the filter with a residual cake.
- The filter cake pressure drop, which is a function of the cake permeability as it builds up on the filter element.

The filter pressure drop affects equipment size (capital cost), operating efficiency, and maintenance costs. Because of the high operating pressure of advanced combustion systems being developed by the DOE, it is not a significant factor. However, for low-pressure applications, pressure drop becomes a critical design consideration.

Filter cake pressure drop can be predicted if data such as particle size distribution, loading, and cake porosity are available. A serious problem is that there is not much data for particles and filter cakes that can be used in these theoretical equations. Both the DOE and industry are

addressing this issue in the clean coal technology demonstration programs. Determining filter cake pressure drop will allow calculations of blowback cleaning requirements and cake cleaning efficiency. This information can be used to optimize the design and operation of blowback systems.

3.2.2 Barrier Filter Design Considerations

Candles are typically hung vertically from the top of each candle, from a horizontal tubesheet. One recent design supports them from the bottom. Various methods are used to secure the candles to the tubesheet, including weights, clamps, and springs. Care must be used in making this connection, since there is a pressure differential across the connection that may cause leaks across the tube to tubesheet seal, as well as the effects of absolute and differential expansion and thermal and mechanical shock during cleaning.

Candles are cleaned by sending a surge of air or inert gas backward through the candle wall. Experience to date has shown that a "pulse" system, wherein a short, high-pressure pulse of gas is injected on the clean side of the candle, apparently works better than a back flow system, where a lower pressure, longer back flow of gas is used. Systems where isolation of elements for cleaning is used require extra filter elements, increasing the filter system costs. Also, the gas used for pulse cleaning is usually much cooler than the filter element, and can cause thermal stress on the elements. However, regenerators have been developed that provide mass thermal storage, so that the back-pulse gas is prewarmed prior to entering the candle element.

A new, clean filter has an intrinsic pressure drop that is a function of face velocity. As the filter is subjected to normal use and cleaning cycles, the pressure drop across the filter will build up until it reaches equilibrium, which will normally be around twice the initial clean pressure drop at equal face velocity (see Figure 3-1). The value of the equilibrium pressure drop is important to the design of the filter as well as the rest of the plant, and should be determined by testing of actual dust, if possible, before final design.

Figure 3-1
Differential Pressure Versus Time

Pressure drop across the candle filter wall can be controlled in several different ways. By varying the wall thickness, the pressure will vary substantially, assuming other factors are held constant. However, wall thickness may be dictated by strength requirements and may not be variable. Porosity can also be varied. Some filters are manufactured with more than one layer, each with a different pore size, the outer layer or skin with smaller pores to prevent small particles from entering the pores.

Although the upper temperature limit of ceramic filters is high, 1200 to 1500 °F, there are technical difficulties in operating at these limits. Special consideration must be given to the design and construction of the filter housing, and often the dusts being filtered have different characteristics at these elevated temperatures. Certain types of ash can sinter at temperatures as low as 1200 °F. A sintered or melted material on a rigid media could present significant difficulties when pulse cleaning.

Ceramic filter elements possess sufficient strength to withstand repeated pulse cleaning. However, they are susceptible to erosion by direct impingement by abrasive particles. Proper filter design can eliminate the threat from "shot blasting" of the elements.

In certain situations, the ceramic filters can be prone to sticky ash or flux attack. If a substantial amount of combustible material and flux is allowed to build up on the filter element, then sintering and weakening of the element can occur.

The DOE development program is aimed at applications that operate at higher temperature (1200 to 1500 °F) and pressure (10 to 25 atm) than most industrial applications. Critical filter material properties at these conditions are tensile strength retention and tensile creep, or microcrack stability. A coordinated program is in place to resolve these fundamental technical issues. This program has led to recent advances in filter element development and feeds into pilot plant testing and demonstration programs. Progress has been reported in both reducing creep above 760 °C (1400 °F) and increasing the ΔT for microcracking.⁷

A significant number of ceramic filters have broken in various DOE experimental and demonstration devices tested at Tidd and the PSDF. Some of the lessons learned include:

- Nearly all of the candle breakage observed at Tidd was attributed to ash bridging in the filter. Ash bridging was strongly affected by the size and temperature of the ash entering the filter. Ash from a partially detuned cyclone (about 7 microns) was more easily removed than the smaller ash, but still difficult to remove at operating temperatures over 790 °C (1450 °F). Ash above a mass mean diameter of 27 microns was easily removed and did not tend to bridge.⁸
- Nearly all of the candle breakage observed at the PSDF was attributed to initial operation of the developmental transport reactor and the transition from propane to coal during startup.⁵
- It is important to prevent ash from entering the inside of the filter candles to avoid blinding them on the inside surfaces. Also, ash accumulation in the inside bottom of candles can induce cracking in the candles.

- It is important to have reliable continuous ash removal from the filter. Ash buildup in the particulate filter hopper resulted in candle breakage.

3.3 BARRIER FILTER MARKETS

In general, barrier filters fill niche markets with special problems. They do not compete in the typical particulate control market against conventional technology, i.e., electrostatic precipitators or fabric filters/baghouses. Barrier filters must be seen as a system offering the user an incentive to justify the higher initial costs for the filters. Table 3-2 lists applications cited for barrier filters.⁹

Table 3-2
Barrier Filter Applications Cited

Source: Ceramic Gas Cleaning	Source: Industrial Filter & Pump Mfg Co.	Source: Cerel Ltd.	Source: Filter Media Consulting, Inc.
Fluidized Bed Combustion	Alumina Scrap Smelting	Gasification of Biomass	IGCC
Diesel Exhaust	Brass and Copper Smelting	Zirconia Production	PFBC
Wood Gasifier	Lead Smelting	Furnace Melting Lead	Calcination
Fumed Silica	Zirconia Processing	Aluminum Scrap Melting	Catalyst Recovery
Bitumen Oil Mist	Metal Oxide Powder	Foundry Applications	Material Recovery
Clinical Waste Incinerator	Wood Bark Incineration	Smokeless Fuel Production	Chemical Industry
RDF Incinerator	Clinical Waste Incinerator	Machine Tool Dust Removal	Catalytic Cracking
	Chemical Wastes	Clinical Waste Incineration	Waste Incineration
	Hazardous Wastes	Chemical Waste Incineration	
	Soil Remediation		

There have been several filters supplied for use in PFBC and IGCC applications in the DOE Clean Coal Technology Demonstration Program. These have included:

- Westinghouse supplied the filter at Tidd. The filter tested at Tidd had three clusters with three tiers each and contained over 350 candles. A similar size vessel using a maximum of 273 candles is to be tested at Wilsonville on a PFBC combustor. Westinghouse also provided the ceramic candle filters for the 95 MWe Piñon Pine IGCC project. Westinghouse has an agreement with Foster Wheeler to design and supply filters for their PFBC clean coal demonstration plants.
- Pall supplied a 56-candle filter that was to be tested at the Tampa Electric Company IGCC plant on a slipstream of fuel gas downstream of the hot gas desulfurization system. Sintered metal candles were to be tested.

3.4 EXPERIENCE IN SIMILAR SERVICE AS SUPERIOR GRAPHITE

The Superior Graphite filter application will be unique due to its large size (designed for 40,000 acfm), the high percentage of carbon in the particulate (>75%), and the relatively high oxygen content (18%) when compared to flue gas. Candle filters have been used to filter high carbon particulate^{4,10}, but generally not at this size range. The application most similar to Superior Graphite was described in a paper at the Second International Symposium on Gas Cleaning at High Temperatures.¹¹

Solid smokeless fuel was manufactured at Coal Products Coventry Homefire Works by a process involving the low-temperature fluidized-bed carbonization of crushed coal. The waste gas produced by this process, amounting to some 17,000 Nm³/h (10,000 scfm) and containing large quantities of tar and fine carbonized coal particles (char), was previously incinerated, and its products of combustion discharged to the atmosphere via a 65-meter (213-foot)-high chimney, resulting in a heavily ash-laden emission.

Even though low-density ceramic filtration had not been employed in any major flue gas cleaning scheme and little practical information was available, the Company considered the technique worth evaluating in the absence of more conventional solutions. In late 1990, a pilot ceramic filter was purchased with the aim of cleaning a side stream of flue gas from the incinerator chimney.

The imposition in June 1991 of a two-part Improvement Order by Her Majesty's Inspectorate of Pollution on the particulate emissions from the incinerator chimney required the fitting of suitable filters to the flue gas ducts of both Works boilers.

The first of the boiler ceramic filters, for the No. 1 boiler, was designed in the light of experience gained in the pilot filter operations. This filter was capable of handling 50,000 Am³/h (30,000 acfm) of boiler flue gas at a normal operating temperature of 270 °C (518 °F) and was designed to operate at a maximum temperature of 400 °C (752 °F). The expected operating pressure drop was 180 to 250 mm (7 to 10 inches) H₂O. The filter house contained 2,592 Cerafil S elements mounted in 72, 36-element, horizontal cassettes.

The filter on No. 1 boiler was commissioned in October 1991. Failures initially occurred in the filter due to the combustion and sintering of high-carbon dust following boiler flame failure, requiring the complete replacement of the ceramic elements. Test rig work indicated that combustion did not occur in the dust at temperatures below 250 °C irrespective of oxygen levels or carbon contents, and at temperatures above 250 °C, combustion was not observed at oxygen levels less than 16%.¹¹ After this test program, the following recommendations were implemented for both filters in July 1992:

- A reduction in both temperature and oxygen content of the flue gas.
- The isolation of the filter immediately following boiler flame failure and the blanketing of the unit with nitrogen.

Filters were subsequently operated on both boilers with only occasional occurrences of ash combustion and sintering following boiler flame failure till mid-1995. At that time the Works switched to a cold process and shut down the hot process facility.

The authors' conclusion about the use of barrier filters, as quoted below, probably holds true for any large scale-application, including the Superior Graphite application.

"The use of small multi-element pilot filter units are an essential stage in determining the suitability of low-density ceramic filters for large scale gas clean-up projects. The analysis of the data obtained during prolonged testing of such filters can give valuable insights into the behaviour of the materials being filtered and provides information necessary for the finalisation of the design of full size units. Even so, problems not encountered even during extensive pilot filter trials, can arise during the operation of full stream units causing possible radical re-design and unexpected expense." ¹¹

4.0 SUPERIOR GRAPHITE'S BARRIER FILTER SYSTEM DESIGN

4.1 KICKOFF MEETING

A kickoff meeting was held at the plant on November 18, 1999. The following ground rules were discussed and agreed upon:

- Locate the filter downstream of the afterburners/gas coolers. Filtering upstream of the afterburner would require filters for each furnace and may not prove completely safe due to the requirements of cooling the combustible gases from the furnaces before filtering.
- Retain, as much as possible, present operating conditions. Changes that affect flows and temperatures, such as the amount of dilution air, would affect the operation of the downstream scrubber.
- The CRADA design conditions will be based on the design production rate temperatures, flows, and loadings. These are based on five furnaces operating. The numbers were verified by Superior Graphite.
- The present cyclone will be retained as a backup to the new filter.

The following issues were also discussed:

- Fan upgrade/replacement – A maximum of 7 inches of water is available with the existing fans. Since the expected pressure drop requirements for the barrier filter will likely exceed this and Superior Graphite would like some margin, fan upgrades or replacement is anticipated.
- Controls upgrade and integration.
- Turndown – Superior Graphite operates anywhere from one to five furnaces. The filter must accommodate the varying flow.
- Capacity factor – Superior Graphite operates 24 hours a day, 365 days a year without any general plant shutdown. Individual furnaces are shut down every 7 to 30 days.
- Upsets – Periodically a major furnace upset occurs, which ejects high-temperature, heavily loaded gas through the cyclone.
- Blowback gas – Nitrogen is available if necessary.
- Space – There is no spare space in the existing furnace building. An adjacent scrubber building has a vacant bay that could accommodate the filter.
- Particulate matter characteristics – Only limited data exist on the particulate matter size distribution and physical characteristics from sampling of the existing particulate collected

from existing control devices. No in-line sampling of particulate was conducted as a part of this conceptual study.

Based on the agreed-upon ground rules and these discussions, a functional specification was prepared and a request for a budget estimate was sent to several vendors. The responses were used as the basis for the conceptual design.

4.2 HOPKINSVILLE PLANT PROCESS DESCRIPTION

The Hopkinsville plant process begins with graphite furnaces, which are fed calcined petroleum coke to produce a high purity carbon product. Operating at temperatures exceeding 2760 °C (5000 °F), this process converts amorphous carbon to graphite and generates a flue gas containing N₂, CO, H₂S, and other sulfur compounds, along with particulate matter emissions. Gases exit the furnaces at temperatures on the order of 1980 °C (3600 °F).

Above each furnace is an afterburner that by air infiltration oxidizes the CO to CO₂ and the H₂S to SO₂ (and some SO₃). At the exit of the afterburner, the total design gas flow is 35,700 pounds per hour at a temperature of about 800 °C. The operating pressure at the furnace exit is ½ inch of water below atmospheric, as a result of the induced draft (ID) fans downstream of the particulate removal processes. There is a port at the inlet end of the afterburner. Air enters the port as part of the afterburner oxygen for combustion.

The gases coming from each afterburner are cooled by diluting with air. Ambient air is drawn into each furnace duct through a damper. Total dilution air added to the afterburner gas at design conditions is 48,300 pounds per hour. With this dilution air, the gases are cooled by mixing to 350 °C (662 °F) design temperature. In operation, the actual temperature range is 250 to 325 °C (480 to 620 °F), with excursions to 375 °C (707 °F).

Table 4-1
Afterburner Gas Composition at Design Conditions

	Lb/hour	Lbmoles/hour	Mole Fraction
Nitrogen	27,300	975	0.807
Oxygen	5,700	178	0.148
Carbon Dioxide	1,020	23	0.019
Sulfur Dioxide	1,250	20	0.016
Sulfur Trioxide	17	0.2	0.0002
Water	200	11	0.010
Particulates (est.)	220	N/A	N/A
Total	35,700	1,207	1.00

Table 4-2
Diluted and Cooled Gas Composition at Design Conditions

	Lb/hour	Lbmoles/hour	Mole Fraction
Nitrogen	64,000	2,286	0.791
Oxygen	16,800	525	0.182
Carbon Dioxide	1,100	25	0.008
Sulfur Dioxide	1,250	20	0.007
Sulfur Trioxide	17	0.2	0.00008
Water	633	35	0.012
Particulates (est.)	220	N/A	N/A
Total	84,000	2,891	1.00

As shown in the flow diagram (Figure 4-1), the cooled afterburner lines are then manifolded together where operation under two separate permits allows alternative particulate and sulfur removal.

Figure 4-1
Plant Flow Diagram

For the first permitted alternative, the gas exits in a direction perpendicular to the manifold to an ID fan and a baghouse. Only one of the furnaces is permitted to process sulfur-bearing raw material while discharging to the baghouse. The baghouse is also used with specialty production.

The second permitted alternative for particulate and sulfur removal is located at the end where the manifold terminates. The 30-inch-diameter duct passes through the wall of the furnace room to be joined with another furnace duct at the entrance to the particulate removal multiclone.

At this point, the estimated gas flow is in the range of 40,000 acfm at 350 °C (662 °F) operating at maximum conditions. The multiclone consists of 48 cyclones and has a total pressure drop of about 2 to 3 inches H₂O. The multiclone occupies a 12 foot x 15 foot x 35 foot high bay in the building. Ducts run from the multiclone to a duct, which is split to the two ID fans. The new ID fan outlet is ducted to the new quench/scrubber, and the old fan outlet is ducted to the old quench

scrubber. A duct with a damper connecting the quench outlets permits operation of both fans through a common scrubber. The old scrubber is retained as a backup to the new scrubber. Operating temperature of the multiclone is limited to 350 °C (662 °F) due to the upper limit on the ID fans. The fans are outside the multiclone building and direct gas to the quench scrubbers.

Gas entering the quench is cooled with scrubber liquor to 63 °C (145 °F). Both the old and new scrubbers have rotary atomizers and a number of mist eliminators. The old scrubber is permitted at 95% SO₂ efficiency, and the new scrubber is permitted at 97.5% SO₂ efficiency.

The new scrubber is located in a scrubber building, and occupies about half of the area. The unoccupied area of the scrubber building has an open bay area about 25 feet x 20 feet x 30 feet high, which could be suitable for the new filter.

4.3 TECHNICAL ISSUES

Several technical issues that are pertinent to the design of the barrier filter for Superior Graphite are discussed below.

Face Velocity – A new, clean filter has an intrinsic pressure drop that is a function of face velocity and the filter media. As the filter is subjected to normal use and cleaning cycles, the pressure drop across the filter will build up until it reaches equilibrium. Too high a face velocity can result in several problems including dust re-entrainment, unstable equilibrium pressure drop, or dust penetration of the filter element. Too low a face velocity increases the size/cost of the filter.

The value of the face velocity is important to the design of the filter as well as the rest of the plant, and should be determined by testing of actual dust, if possible, before final design. In this conceptual design study, the vendors used their judgment and experience to select a face velocity.

Carbon Content of Ash – Failures occurred in the Coventry Homefire Works filter due to the combustion and sintering of high carbon dust following boiler flame failure, allowing unburned carbonization dust into the filter. The Superior Graphite's carbon content of the dust and oxygen content of the flue gas would be similar to the Coventry Homefire Works during boiler flame failure but would be afterburned, thereby being free of volatiles. Whether Superior Graphite's dust will be susceptible to combustion and sintering must be determined by testing. Periodically an upset in a furnace at Superior Graphite will cause the contents to be blown through to the filter. For this reason, the design does include the ability to isolate the filter during upsets and the blanketing of the unit with nitrogen.

Particle Loading and Size – With the multiclone at Superior Graphite bypassed, the particulate loading was estimated at 0.6 grains/acf with a mass mean diameter of 34 microns. Using dilution air to cool the flue gas results in lower loadings than from a typical flue gas. The typical loading at Coventry Homefire Work's filter was 3.0 grains/acf. Lower loadings result in longer blowback cycles and less dust handling.

Operating experience has shown that a coarser particle size distribution is more easily removed. At Tidd, ash from a partially detuned cyclone (about 7 microns) was more easily removed than the smaller ash, but still difficult to remove at operating temperatures over 790 °C (1450 °F). Ash above a mass mean diameter of 27 microns was easily removed and did not tend to bridge.⁸ At the PFBC plant in Wakamatsu, the cyclones have been completely removed since coarse particles are easier to filter.¹²

Sticky Ash or Flux Attack – The major causes of sticky ashes are eutectics caused by alkalis in the ash. At Tidd, high alkali coal ashes above 1500 °F in oxidizing conditions resulted in sticky ash and bridging.⁸ The petroleum coke ashes are low in alkali. Alkali concentrations in coal ash range from 2 to 3%, whereas alkali in coke ash ranges from nil to <1%. Also, the ppm level of alkali from coke combustion compared to coal combustion is one to two orders of magnitude lower, due to the low ash concentration (<1%) in coke. Operating in an oxidizing condition below 1300 °F should preclude sticky solids.

Candle Breakage – Candle filter elements, being rigid, can also be susceptible to brittle failure, especially at the high temperatures and pressures used in PFBC and IGCC power generation. A significant number of ceramic filters have broken in various DOE experimental and demonstration devices tested at Tidd and the PSDF. Nearly all of the candle breakage observed at Tidd was attributed to ash bridging in the filter,⁸ and at the PSDF it was attributed to initial operation of the developmental transport reactor and the transition from propane to coal during startup.⁵ Other root causes of failures include ash removal from pressurized systems and sintering of the candles. Superior Graphite, operating at relatively low temperature and pressure, should be able to control many of these root causes.

Ability to Remove SO₃ – High levels of SO₃ passing into wet scrubbers have been shown to cause acid mist carryover and potential stack opacity problems.¹³ Two potential causes of the opacity problem at Superior Graphite are particulate passing through the multiclone and a relatively high SO₃ concentration in the flue gas (80 ppm). The barrier filter will reduce particulate carryover. However, there is expected to be little SO₃ removed by the filter without the addition of separate absorbent material. Some test work has been done on injecting absorbents into barrier filters for SO₃ removal,¹⁴ but little if any commercial experience is available.

Pilot Plant Testing – The Superior Graphite filter application will be unique due to its large size (designed for 40,000 acfm), the high percentage of carbon in the particulate (>75%), and the relatively high oxygen content (18%) when compared to flue gas. While guidance can be obtained from the design and operation of the Coventry Homefire Works filter, there are enough differences (coal versus coke as a carbon source, flue gas versus dilution gas, 30,000 acfm versus 40,000 acfm) that it would be prudent to run pilot plant tests on the Superior Graphite dust. The use of small multi-element pilot filters in a slipstream at the Hopkinsville plant can give valuable insights into the behavior of material being filtered and provides information necessary for the finalization of the design of full-size units.¹¹

An objective of the pilot plant tests would be to verify for a particular filter media the face velocity that can be used while maintaining a stable pressure drop without dust re-entrainment or penetration. A second objective would be to determine the conditions necessary for preventing the combustion of solids on the filter elements in Superior Graphite's outlet gases.

Capacity – Typical barrier filters in industrial applications usually filter gas streams of less than 10,000 acfm. However, several larger sized units have been built, with the largest a 2 x 54,000 acfm at the PFBC unit in Wakamatsu, Japan. The Superior Graphite unit, at 40,000 acfm, will be one of the largest units built.

Reliability – In the past, reliability has been an issue with barrier filters, but much has been learned. At the Coventry Homefire Works, after an initial period of candle failures during upset conditions, reliable operation of the filters was obtained for several years before the process shut down. Superior Graphite's operating conditions are not severe for barrier filters. Particulate loading, temperature, and face velocity under typical operating conditions are not particularly high for this type of filter. Under normal operating conditions, reliability should be maintained. However, most candle failures occur during abnormal operating conditions such as startup, shutdown, and upsets. Superior Graphite will be as susceptible to these as others.

4.4 BARRIER FILTRATION SYSTEM PROCESS DESIGN

Referring to the block flow diagram of Figure 4-2, the existing multiclone will be retained as a parallel backup particulate control device. The filter retrofit ductwork will join the off-gas manifold with insertion of a cross before it exits the furnace building. Between the cross and the existing multiclone, a man-safe wafer damper (V-1) will be used to isolate the multiclone during filter operation. All furnace ducts will be re-routed to join the cross. Downstream of the multiclone, in the duct coming from the multiclone building, another wafer damper (V-2) will be installed to achieve complete isolation of the multiclone. Man-safe wafer dampers are leak-proof butterfly-type dampers, sealed with external air pressurization. The man-safe designation entails preventing escape of toxic gases into a confined area.

At the cross on the multiclone inlet, the left stub ductwork will be routed through the walls to reach the bay of the scrubber building. The filter vessel (F-1) will be installed in the scrubber building high bay. At the duct entering the filter vessel, a wafer damper (V-3) will be installed, and at the filter exit, a second wafer damper (V-4) will be installed. These valves will be used to isolate the filter. The filter system will be designed with an active protection system, which senses high temperatures, closes the isolation valves, opens the multiclone valves, and purges the filter vessel with nitrogen. The purpose of using nitrogen is to reduce the oxygen level and quench any combustion that could start within the filter vessel. The valves can also isolate the filter vessel for periodic maintenance. During maintenance, the filter vessel will be purged with air, and confined entry procedures will be in effect. Nitrogen and air are supplied from a high-pressure feed line through a control valve. The filter outlet will be ducted outside to the ID fans' common suction line.

Figure 4-2
Barrier Filter System
Block Flow Diagram

Dust collected by the barrier filter will be removed from the bottom cone of the filter vessel by screw conveyor operation. Filter dust will be conveyed to a closed bin, which is outside and underneath the adjacent bag house. Periodically the bin contents will be disposed off site.

Immediately downstream of the valve in the ductwork coming from the existing multicloner, a tee will be installed in the common suction line for the dual ID fans (FN-1, FN-2). The tee stub will be joined with the duct leading from the filter vessel contained in the scrubber building.

This retrofit design provides the following capabilities:

- Retain existing multicloner as a backup for the filter.
- Isolate the filter for maintenance.
- Sense upsets, isolate the filter, and purge with nitrogen.
- Retain existing duct configuration downstream of filters to ID fans.
- Retain dual ID fans with flexibility in turndown.
- Provide dual quench capability.
- Retain the old quench/scrubber for system backup.

4.5 FILTER EVALUATION

A functional specification and a request for a budget estimate were sent to four vendors. Responses were received from three vendors proposing to utilize candle filters for this application. This section provides a review of the vendors' response and a rationale for the selection of the filter used in the conceptual design.

4.5.1 Particulate Filter Functional Specification

Capacity Factor	Plant operates 24 hours a day, 365 days a year	
Installation Location	Indoor location in scrubber building, two bays about 15 feet x 15 feet x 30 feet high	
Gas Flow	84,000 lb/hour, 220 lb/hour particulates, 0.6 grains/acf	
Gas Composition	Nitrogen	0.791 mole fraction
	Oxygen	0.182 mole fraction
	CO ₂	0.008 mole fraction
	SO ₂	0.007 mole fraction
	SO ₃	0.00008 (80 ppmv)
	H ₂ O	0.012 mole fraction
Pressure	Inlet @ 2 inches w.g. negative	
Temperature	Design temperature 350 °C (662 °F)	
	Normal operating 250 to 325 °C (480 to 620 °F)	
	Excursions to 375 °C (707 °F)	
Particulate Characteristics	Granular, >75% carbon, balance ash	
Particulate Distribution	95%	<66 micron
	90%	<56 micron
	80%	<50 micron
	50%	<34 micron
	25%	<10.5 micron
	10%	<6.5 micron
Blowback	100 psig air (blowback gas supplied by others)	
Inerting Provisions	Nitrogen as required (nitrogen supplied by others)	
Maintenance Provisions	Air purging and confined entry protection	
Filter System I&C	a) As supplied with filter	

- b) Temperature excursion monitors directing isolation valve closure and vessel flooding with inerting gas.

Material Considerations Sulfuric acid dew point estimated at 160 °C (320 °F)

4.5.2 Particulate Filter Selection

Table 4-3 shows a summary of the budget estimate received from the vendors. Responses were received from three of the four vendors solicited.

Table 4-3
Filter Data Summary

Vendor	No. 1	No. 2	No. 3
Type	Candle	Candle	Candle
Material	Aluminosilicate	SS 316L	Silicon carbide
Element Size	60/40x1500 mm	100 in L	60/40x1500 mm
Face Velocity, feet per minute	8	6	5.5
ACFM/Candle	24	18	16.6
Number	1,632	2,088	2,400
Estimated Candle Life	3 years	3 years	15,000 hours
Delta P, inches w.g.	20	15	18
Performance	99.9%	<1 ppm	<5 mg/Nm ³
Number of Filter Vessels	1	2	2
H, feet	15	35	14
L, feet	20		21
W, feet	13	9 dia	14
Cost	\$907,063	\$2,500,000	\$1,338,733
Exclusions	Shipping Field Erection Service Platform Startup Spares	Insulation	Insulation Supporting Structure Service Platform Field Erection Startup, Spares

Vendor 1 proposed using candles manufactured from low-density vacuum formed chopped aluminosilicate fibers. At their proposed face velocity of 8 feet/minute, the number of filter elements required would be 1,632. These would be packaged into a single filter housing approximately 20 feet x 13 feet x 15 feet high.

Vendor 2 proposed using candles manufactured from a classified process to create a seamless, porous stainless steel membrane. At their proposed face velocity of 6 feet/minute, the number of filter elements required would be 2,088. These would be packaged into two filters approximately 9 feet in diameter x 35 feet high.

Vendor 3 proposed using candles manufactured from a coarse porous support body of silicon carbide ceramically bonded with a fine filtering membrane of mullite. At their proposed face velocity of 5.5 feet/minute, the number of filter elements required would be 2,400. These would be packaged into two filter housings approximately 21 feet x 14 feet x 14 feet high.

Barrier filters are inherently efficient, and can achieve less than 5 ppm of particulate emissions (approximately equivalent to 0.0025 grs/scf).⁵ All three vendors are projecting emissions of less than 5 ppm with efficiencies of 99.7% or better. The three vendors also projected pressure drops ranging from 15 to 20 inches of water. A maximum of 7 inches of water is available. Superior Graphite wants some margin, and a fan upgrade is included in the design.

All three filter element materials have been utilized by their respective vendors in barrier filter applications. High-density silicon carbide is the most common type of filter element and has been tested extensively in the DOE hot gas cleanup program for coal gasification and pressurized fluidized-bed combustion (PFBC). These applications are at a higher temperature (1200 to 1500 °F) and pressure (10 to 25 atm) than the Superior Graphite applications. For these applications, the silicon carbide filter elements displayed better strength retention and creep stability than other candidates did.⁷

Ceramic fiber candle filters have been developed to provide a material that is more flexible than monolithic ceramics and does not fail in a brittle manner but is not as strong. Low-density aluminosilicate fiber elements have been utilized widely in the United States and Europe. This element is similar to the Cerel elements utilized at the Coventry Homefire Works.

Sintered stainless steel elements have also been utilized in several applications. Failures were reported in a reducing gasification atmosphere due to sulfur attack. However, this should not occur in an oxidizing atmosphere. Due to the high SO₃ concentration (80 ppm) in the Superior Graphite flue gas and a relatively high dew point, acid corrosion of the filter elements could be a concern.

Face velocity (acfm flue gas/ft² filter area) is an important parameter since it determines the number of candles needed, the pressure drop, and the size/cost of the filter. It is difficult, a priori, to predict face velocity, and testing is usually performed. In this conceptual design study, the vendors used their judgment and experience to select a face velocity.

Vendor 1's design results in a face velocity of 8 feet/minute, which is similar to that recommended for the Coventry Homefire Works filter – 7.2 feet/minute.¹¹ This results in 1,632 filter elements, which can be packaged into a filter that would fit into the available bay. Vendor 2's design results in a face velocity of 6 feet/minute, requiring 2,088 filter elements, which are packaged into two filters and would require expanding the bay to 70 feet high in order to remove the filter elements. Vendor 3's design results in a face velocity of 5.5 feet/minute, requiring 2,400 filter elements, which are packaged into two filter vessels and would require expanding the bay outward.

Vendor 1's proposed cost is less than that of Vendor 3, primarily because of fewer candles. On a per candle basis, the costs of both are approximately the same. Vendor 2's cost is higher both absolutely and on a per candle basis.

Predicted removal efficiency and pressure drop proposed by all three vendors are similar. Vendors 1 and 3 proposed ceramic filter elements that are more appropriate for the high SO₃ conditions than the sintered stainless steel elements. Because of this and the higher costs, Vendor 2 was eliminated from further consideration. The selection of either Vendor 1 or Vendor 3 is considered premature without having the results of a pilot test program to identify the performance characteristics of their filter elements in the Superior Graphite application. Therefore, conceptual designs and capital cost estimates have been generated for both options.

4.6 OTHER SYSTEMS AND EQUIPMENT

4.6.1 ID Fan Functional Specification

The following functional specification is based on total flow through the system. If the specification applies to multiple fans, the flows should be assigned proportionately to each fan.

Table 4-4
Fan Functional Specification

Operating Temperature	Design temperature: 350 °C (662 °F) Normal operating: 250-325 °C (480-620 °F) Excursions to 375 °C (707 °F)
Site Altitude	568 feet
Static Pressure	36 inches w.g. at maximum flow
Total Gas Flow	84,000 lb/hour or 38,000 acfm with maximum furnace output
Inlet Gas Composition and Properties	
Gas Density	0.035 lb/ft ³
Molecular Weight	28.99
Particulates	Particulate-free when filter is on-line When gas is bypassed through multiclone: 8 micron particles containing >75% C Loading: 0.2 grains/acf
Gas Composition, Volume Percent	
Nitrogen	79.1
Oxygen	18.2
CO ₂	0.8
SO ₂	0.7
SO ₃	0.008 (80 ppmv)
H ₂ O	1.2
Operating Voltage	480 Vac, 3 phase
ID Fan I&C	Supplied by vendor
Motor Control Center	Supplied by others
Material Considerations	160 °C sulfuric acid dewpoint

In response to the functional specification, Howden Fan Company provided a budget estimate to retrofit the existing housings with new rotors, resulting in a performance upgrade.

4.6.2 Damper and Ducting Arrangement

As required, the filter will be connected with 36-inch insulated steel duct. This will include:

- Duct to multiclone inlet
- Duct to filter
- Duct from filter
- Duct to ID fan
- Duct from ID fan to quench

The isolation dampers are of the wafer-man-safe type with a design pressure of 36.0 inches w.g. Each 36-inch damper has an electric actuator and its own seal air fan. Zero leakage is specified with the seal air fan running. Composite expansion joints are also provided, with operating temperature of 707 °F at 36.0 inches w.g.

4.6.3 Nitrogen Inerting System

The nitrogen supply for inerting the filter is located on-site. A nitrogen compressor rated at 100 scfm is used to fill a storage tank at 150 psig. Piping to the filter is through 4-inch schedule 40 steel pipe. A fast-opening ball valve is controlled to dump the tank contents into the filter if an unsafe condition is present.

4.7 CONCEPTUAL DESIGNS

4.7.1 Vendor 1 Design

The conceptual design utilizing the barrier filter design supplied by Vendor 1 is characterized by its more compact size. This results in the filter housing being able to be installed in the bay of the scrubber building without major structural expansion of the building. Figure 4-3 is the plot plan for this design.

Particulate Filter Description

Figure 4-4 is an isometric drawing of the particulate filter housing. The overall dimensions of the housing are 7.6 meters (25 feet) long by 5.5 meters (18 feet) wide by 4.6 meters (15 feet) high. The filter is located in the vacant bay of the scrubber building on the ground floor. The filter housing from Vendor 1 is relatively compact, and can fit within the scrubber building bay. The filter housing is fabricated of mild steel, insulated with a 1-inch ceramic blanket. The dirty gas inlet to the filter enters through the south side of the scrubber bay and is joined with a transition joint to the filter housing.

Figure 4-3
Vendor 1 Design
Plot Plan

PROGRESS PLOT
 6-23-00

5763021.XRSG-1-DW-253-002-001.DGN

REVISION	DATE	DESCRIPTION
1	08/23/00	INITIAL ISSUE
2	08/23/00	INCORPORATED COMMENTS

DATE	BY	FOR
08/23/00	JEV	CONCEPTUAL DESIGN
08/23/00	JEV	FOR CONSTRUCTION

DATE	BY	FOR
08/23/00	JEV	CONCEPTUAL DESIGN
08/23/00	JEV	FOR CONSTRUCTION

DATE	BY	FOR
08/23/00	JEV	CONCEPTUAL DESIGN
08/23/00	JEV	FOR CONSTRUCTION

DATE	BY	FOR
08/23/00	JEV	CONCEPTUAL DESIGN
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DATE	BY	FOR
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DATE	BY	FOR
08/23/00	JEV	CONCEPTUAL DESIGN
08/23/00	JEV	FOR CONSTRUCTION

DATE	BY	FOR
08/23/00	JEV	CONCEPTUAL DESIGN
08/23/00	JEV	FOR CONSTRUCTION

PARSONS
 PARSONS INFRASTRUCTURE & TECHNOLOGY GROUP, INC.
 PROJECT NUMBER: 5763021.XRSG-1-DW-253-002-001

CLIENT/PROJECT TITLE
 APPLICATION OF A BARRIER FILTER
 AT A HIGH PURITY SYNTHETIC
 GRAPHITE PLANT

GENERAL ARRANGEMENT
 EQUIPMENT LAYOUT
 VENDOR NO. 1

SCALE: 1/4" = 1'-0"
 PROJECT NO. 5763021.XRSG-1-DW-253-002-001

GRAPHIC SCALE IN FEET
 0 5 10

PLAN

Figure 4-4
Vendor 1 Design
Filter Vessel Isometric

The filter housing is comprised of 12 filter modules, two columns of six rows, each containing a tube sheet 36 inches by 66 inches. Fibrosic filter candles are hung from each of the tube sheets, providing 1,632 total candles, 136 candles per module. Gas enters the outer circumference of the candles at a face velocity of 8 feet per minute, and exits above the tube sheet. The clean gas from each module exits the filter housing through a 6-inch flange, and is then manifolded across the top of the housing with a 24-inch duct. The gas leaves the scrubber building through the east wall of the bay to the ID fan suction duct.

The particulate from the dirty gas is trapped by the Fibrosic candles and is periodically removed by reverse pulsing. At a preset pressure drop or approximately once per hour, 12 liters of air per candle is blown back. The particulate falls into the hopper bottom of the filter housing and is transported by screw conveyor to the west end of the housing, directed south through the bay wall. From there, the dust is conveyed to beneath the baghouse building, and unloaded into a bin for disposal. The pulse system supplied by the filter vendor consists of a 50-cubic-foot tank for air storage at 100 psig. A blowback valve for each filter module is controlled by either a timer or by a differential pressure monitor/controller. Air for the blowback system is supplied from an on-site compressor having a capacity of 400 scfm.

Equipment Relocation and Structural Changes

The following changes from the existing plant structure and equipment configuration will be incurred with the installation of the Vendor 1 filter system:

- Cut the 30-inch and 24-inch manifold ducts, adjust plenums, install cross duct.
- Run 36-inch duct out west wall of furnace building adjacent to baghouse platform, then down and north into scrubber south wall. 36-inch penetration.
- Cut west wall of scrubber building sized to accommodate full width and height of filter vessel.
- Construct extended shed roof enclosure extending from scrubber building girder BB south 15 feet, west 12 feet, and 30 feet high.
- Remove and relocate rotary atomizer pump, rotary atomizer recycle tank, associated feed/drain piping, and other equipment from bay area to shed roof enclosure.
- Run pneumatic conveyor from dust collector of filter through south wall across open area to collection bin below baghouse. Requires 24-inch south wall penetration.
- Run 36-inch duct from top of filter vessel to elevation 17 feet and through east wall of scrubber building. Cut existing duct above wye and insert tee duct. Connect 36-inch through transition to tee stub.
- Cut existing inlet and outlet lines to multiclone to install damper valves.

Other Process Equipment

- Fans will be upgraded per Howden Fan quotation and recommendations. This will include new fan rotors, while retaining existing motors and motor control centers.

- Nitrogen source will be excess capacity of on-site nitrogen plant. Nitrogen compressor to be located in new shed extension on west side. 3,000-cubic-foot nitrogen storage tank to be outside.
- Air compressor for blowback to be located in new shed extension on west side. Air storage tank to be outside.
- Additional electrical requirements (480/60/3 ph). Load center to be located within bay. Raceways and wiring as required.
 - Nitrogen compressor 20 hp (15 kW)
 - Air compressor 25 hp (20 kW)
 - Wafer damper valves 1 hp (1 kW)
 - Filter pulse controls 2 kW
 - Nitrogen purge 1 kW
 - Misc. I&C, house 20 kW

4.7.2 Vendor 3 Design

The conceptual design utilizing the barrier filter design supplied by Vendor 3 is characterized by its required large footprint, due to having two filter vessels, each 26 feet by 19 feet in size. This results in there being no space available in the bay of the scrubber building, major structural expansion of the building, and disruption of the surrounding area. Figure 4-5 is the plot plan for this design.

Particulate Filter Description

Figure 4-6 is an isometric drawing of the particulate filter housing. The overall dimensions of the housing are 7.9 meters (26 feet) long by 5.8 meters (19 feet) wide by about 5 meters (16 feet) high. The two filter vessels are located in the vacant bay of the scrubber building, but due to their size, the south and west walls of the bay will be removed up to elevation 30 feet. Equipment, piping, and wiring will be removed and relocated. Shed roof shelter extensions will be constructed out approximately 15 feet west and 25 feet south to accommodate the filter housings. As the southward expansion will interfere with access to the pumps and tanks beneath the existing dust collector (baghouse), the filter vessels will be elevated 8 feet above ground level.

The filter housing is fabricated of mild steel, insulated with a 1-inch ceramic blanket. The dirty gas inlet to the filter enters through the south side of the scrubber bay and is joined with a transition joint to the filter housing.

NOTES 2 1 00

Figure 4-5 Vendor 3 Design Plot Plan

PROGRESS PLOT
5-23-00

5752400 XRS-1-DW-253-002-101.DGN

NO.	DATE	REVISION	BY	CHKD	APP'D
1	5/23/00	INITIAL ISSUE	XY		
2	5/23/00	REVISION	XY		
3	5/23/00	REVISION	XY		
4	5/23/00	REVISION	XY		
5	5/23/00	REVISION	XY		
6	5/23/00	REVISION	XY		
7	5/23/00	REVISION	XY		
8	5/23/00	REVISION	XY		
9	5/23/00	REVISION	XY		
10	5/23/00	REVISION	XY		

CONCEPTUAL DESIGN
UNIT FOR
CONSTRUCTION

DESIGNED BY
DATE
CHECKED BY
DATE
APPROVED BY
DATE

PARSONS
TRANSMISSION INFRASTRUCTURE & TECHNOLOGY GROUP, INC.
10000 WILSON AVENUE
DALLAS, TEXAS 75243

APPLICATION OF A BARRETT FILTER
AT A HIGH PURITY SYNTHETIC
GRAPHITE PLANT

GENERAL ARRANGEMENT
EQUIPMENT LAYOUT
VENDOR NO. 3

XRS-1-DW-253-002-101
REV A

Figure 4-6

Vendor 3 Design
Filter Vessel Isometric

Each filter housing contains 1,200 filter candles. Silicon carbide filter candles are hung from tube sheets, providing 2,400 total candles. Gas enters the outer circumference of the candles at a face velocity of 5 feet per minute, and exits above the tube sheet. The dirty gas leaves the 36-inch duct and enters the filter housings through 12-inch by 6-inch flanged ports (three in each housing). Clean gas from each vessel exits the filter housing through similar 12-inch by 6-inch flanged ports at the opposite end, and is manifolded with another 36-inch duct. The gas leaves the scrubber building through the east wall of the bay to the ID fan suction duct.

The particulate from the dirty gas is trapped by the SiC candles and is periodically removed by reverse pulsing. At a preset pressure drop or approximately once per hour, 12 liters of air per candle is blown back. The particulate falls into the hopper bottom of the filter housing and is transported by screw conveyor to the west end of the housing, directed south through the bay wall. From there, the dust is conveyed to beneath the baghouse building, and unloaded into a bin for disposal. The pulse system supplied by the filter vendor consists of a 50-cubic-foot tank for air storage at 100 psig. A blowback valve for each filter module is controlled by either a timer or a differential pressure monitor/controller. Air for the blowback system is supplied from an on-site compressor having a capacity of 400 scfm.

Equipment Relocation and Structural Changes

The following changes from the existing plant structure and equipment configuration will be incurred with the installation of the Vendor 3 filter system:

- Remove west and south walls of scrubber building up to elevation 30 feet.
- Construct extended shed roof enclosures on west and south sides of scrubber building. West side enclosure to be extended 15 feet. South side enclosure to be extended to meet baghouse, effectively integrating baghouse, scrubber building, and furnace building up to elevation 30 feet.
- Remove and relocate equipment and structures interfering with scrubber building extension.
- Remove and relocate rotary atomizer pump, rotary atomizer recycle tank, associated feed/drain piping, and other equipment from bay area to north end of west side shed roof enclosure.
- Provide steel structure for filter vessels, resulting in 8-foot-high access clearance beneath filter vessels.
- Cut the 30-inch and 24-inch manifold ducts, adjust plenums, install cross duct.
- Run 36-inch duct out west wall of furnace building adjacent to baghouse platform, then down and north into filter vessel area.
- Run pneumatic conveyor from dust collector of filter across south of scrubber building to collection bin below baghouse.
- Run 36-inch duct from top of filter vessel through east wall of scrubber building. Cut existing duct above wye and insert tee duct. Connect 36-inch duct through transition to tee stub.

- Cut existing inlet and outlet lines to multiclone to install damper valves.

Other Process Equipment

- Fans will be upgraded per Howden Fan quotation and recommendations. This will include new fan rotors, while retaining existing motors and motor control centers.
- Nitrogen source will be excess capacity of on-site nitrogen plant. Nitrogen compressor to be located in new shed extension on west side. 6,000-cubic-foot nitrogen storage tank to be outside.
- Air compressor for blowback to be located in new shed extension on west side. Air storage tank to be outside.
- Additional electrical requirements (480/60/3 ph). Load center to be located within bay. Raceways and wiring as required.
 - Nitrogen compressor 20 hp (15 kW)
 - Air compressor 25 hp (20 kW)
 - Wafer damper valves 1 hp (1 kW)
 - Filter pulse controls 2 kW
 - Nitrogen purge 1 kW
 - Misc. I&C, house 20 kW

5.0 COST ESTIMATE

The estimate basis for the U.S. DOE Superior Graphite Plant Filter Retrofit is as follows.

Capital Costs

- This is a conceptual estimate for the retrofit of a furnace off-gas stream with a barrier filter.
- The accuracy of this estimate is $\pm 30\%$.
- All costs in the estimate are expressed in year 2000 dollars. Escalation is not included.
- The quantities in the estimate were supplied by others, and costs are based on vendor budgetary quotes, Parsons E & C database, and other current information
- Allowance for any contaminated soil disposal is not included.
- All environmental permitting and project licensing to be obtained by owner.
- All risk insurance included in contractor's indirect costs.
- Building permits not included.
- Bonds, including performance, payment, and retainage, are excluded.
- Project-specific errors and omissions insurance policy not included.
- Craft hourly rate includes base rate, union fringe benefits, payroll insurances, taxes, indirect costs, and overhead/profit.
- Estimate includes a 25% contingency.
- Owner's costs are not included.

Operating & Maintenance

- Estimated life of the candles for Vendor 1 under normal conditions is 3 years. The cost to replace one complete set of candles in year 2000 dollars is \$375,000. Gasket replacement any time a candle is removed costs \$33/set, or \$53,850 for complete candle replacement.
- Estimated life of the candles for Vendor 3 under normal conditions is greater than 15,000 hours. The cost to replace one complete set of candles in year 2000 dollars is \$550,000.
- Rotating equipment would require normal scheduled preventative maintenance and visual inspections.

Cost Estimate for Vendor 1 Design

Table 5-1 is the detailed estimate, and Table 5-2 is the equipment list.

Cost Estimate for Vendor 3 Design

Table 5-3 is the detailed estimate, and Table 5-4 is the equipment list.

Table 5-1
Superior Graphite Plant Filter Retrofit CRADA
Detailed Estimate for Vendor 1 Design

CLIENT: U.S. DEPT. OF ENERGY
PROJECT: SUPERIOR GRAPHITE PLANT FILTER RETROFIT
DESCRIPTION: BARRIER FILTER INSTALLATION
W. O. NO: 737324-00100

ESTIMATED: EVS
CHECKED: EVS
REVISED: EVS
REVISED: EVS

DATE: 26-Apr-00
DATE: 29-Jun-00
DATE: 14-Aug-00

FILE: C:\GRAPHITE\FILTER\CLIENT.XLS

ITEM NO.	DESCRIPTION	QUANTITY UNIT	TOTAL MANHOURS	MATERIAL COST	LABOR COST	TOTAL COST
VENDOR 1 SCENARIO						
EQUIPMENT						
	BARRIER FILTER MODULE (F1) w/ INSTRUMENTS	1 EA	380	907,100	30,400	937,500
	1668 Candle at 8 FPM. 14.5' H x 20' L x 6' W					
	BARRIER FILTER PLATFORM	1 EA	119	6,410	9,520	15,930
	Grating, Handrail, Stairs					
	PNEUMATIC CONVEYOR	1 EA	112	8,800	8,960	17,760
	From Filter to Baghouse, 44					
	ID FAN UPGRADE (FN1-A, FN1-B) INCL. HOUSING M	2 EA	1,056	76,000	84,480	160,480
	19,000 CFM, 36" SP. Retrofit wheel, 66.5" dia, 131 BHP @ 1750 rpm					
	COMPRESSOR (N2-1), 100 CFM, 150 PSI w/ 3000 SCF	1 EA	35	17,330	2,800	20,130
	Nitrogen Supply					
	COMPRESSOR (BB-1), 400 CFM, 100 PSI w/ 1000 SCF	1 EA	66	49,650	5,280	54,930
	Compressed Air Blowback System					
	COMPRESSOR FOUNDATIONS	2 EA	81	880	6,480	7,360
	INSTALL OVERHEAD DOOR (INCLUDES CUTTING O	1 EA	128	2,000	10,240	12,240
	SUBTOTAL		1,977	1,068,170	168,160	1,226,330
DUCTWORK & DAMPERS						
DAMPERS & EXPANSION JOINTS						
	DAMPERS (V-1), 30" DIA., 0% LEAK, SEAL AIR, M.O.	1 EA	53	14,810	4,240	19,050
	DAMPERS (V-2,3,4), 36" DIA., 0% LEAK, SEAL AIR, M.	3 EA	177	49,550	14,160	63,710
	EXP. JOINTS, 36" DIA.	4 EA	106	11,250	8,480	19,730
	BUILDING DUCT PENETRATIONS	2 ALW	141	1,000	11,280	12,280
DUCT PLATE & STIFFENERS						
	FILTER MANIFOLD	1 EA	44	21,000	3,520	24,520
	DUCT, 3/16" X 36" DIA.	100 LF	211	12,500	16,880	29,380
	ELBOW, 3/16" X 36" DIA.	2 EA	38	2,250	3,040	5,290
	TEE, 3/16" X 36" DIA.	1 EA	25	1,500	2,000	3,500
	CROSS, 3/16" X 30" DIA.	1 EA	26	1,560	2,080	3,640
	DUCT SUPPORT STEEL (MISC HANGERS)	1,600 LBS	53	1,920	4,240	6,160
	INSULATION, CAL SIL W/JKT, 3" THICK	100 LF	440	9,170	35,200	44,370
	PAINT	432 SF	10	70	800	870
	SUBTOTAL		1,324	126,580	106,920	232,500
PIPING SYSTEMS						
NITROGEN PIPING						
	PIPE, 4" (COMPOSITE)	50 LF	65	630	5,200	5,830
	CONTROL VALVE, 4"	1 EA	13	3,500	1,040	4,540
	PAINT	1 ALW	4	30	320	350
AIR PIPING						
	MANIFOLD PIPE, 6" (COMPOSITE)	1 ALW	358	910	28,640	29,550
	PIPE, FLANGED, 2" X 12"	12 EA	53	200	4,240	4,440
	CONTROL VALVE, 2"	12 EA	33	4,200	2,640	6,840
	PAINT	1 ALW	4	30	320	350
	SUBTOTAL		530	9,500	42,400	51,900

Table 5-1 (Cont'd)
Superior Graphite Plant Filter Retrofit CRADA
Detailed Estimate for Vendor 1 Design

ELECTRICAL (ASSUMES EQUIPMENT TO BE POWERED IS WITHIN 100' OF SOURCE)					
SWITCHGEAR LINE-UP	1 EA	70	200,000	5,600	205,600
MOTOR CONTROL CENTER	1 EA	18	8,000	1,440	9,440
RACEWAY & WIRING (POWER & CONTROL) FOR THE FOLLOWING:					
FILTER MODULE (DISTRIBUTION / PLC POWER)	1 ALW	23	230	1,840	2,070
SCREW CONVEYORS	1 ALW	85	900	6,800	7,700
DAMPERS, SEAL AIR FANS, & CONTROL VALVES	1 ALW	377	3,970	30,160	34,130
NITROGEN COMPRESSOR	1 ALW	54	760	4,320	5,080
BLOWBACK COMPRESSOR	1 ALW	83	1,830	6,640	8,470
SUBTOTAL		710	215,690	56,800	272,490
INSTRUMENTATION (CONTROL & INDICATION)					
PROGRAMMABLE LOGIC CONTROLLER	1 LT	26	12,000	2,080	14,080
CONDUIT, 1 1/2" RGS (COMPOSITE)	500 LF	110	1,090	8,800	9,890
CABLE, 8 PR #18 TWSD	1,000 LF	20	610	1,600	2,210
TERMINATIONS	64 EA	14	40	1,120	1,160
SUBTOTAL		170	13,740	13,600	27,340
RELOCATIONS & MISCELLANEOUS					
RELOCATE ATOMIZER RECYCLE TANK & PIPING	1 ALW	211		16,880	16,880
RELOCATE ATOMIZER RECYCLE PUMP & PIPING	1 ALW	141		11,280	11,280
RELOCATE MISCELLANEOUS ELECTRICAL INTERFE	1 ALW	138		11,040	11,040
MODIFY EXISTING MONORAIL FOR RELOCATIONS	1 ALW	138		11,040	11,040
ENCLOSURE FOR TANK, 12' X 16' X 30' H W/FOUNDA	1 ALW	443	8,250	35,440	43,690
HAZMAT DISPOSAL	1 ALW		10,000		10,000
SUBTOTAL		1,071	18,250	85,680	103,930
SUBTOTAL DIRECT COSTS		5,782	\$ 1,451,930	\$ 462,560	\$ 1,914,490
ENGINEERING					\$ 287,170
CONTINGENCY (25%)					\$ 550,420
TOTAL DIRECT COSTS VENDOR 1 SCENARIO					\$ 2,752,080
SPARE CANDLES					\$ 56,000
OTHER SPARE PARTS					\$ 44,000

Table 5-2
Superior Graphite Plant Filter Retrofit CRADA
Equipment List for Vendor 1 Design

Identifier	Nomenclature	Description	Vendor/Source
F-1	Barrier Filter Module	1668 candles at 8 fpm. Module size 14.5' h, 20' l, 6' w Screw conveyor to outside unloading hopper	Filter Vendor 1
FN-1-A, FN-1-B	ID Fan Upgrade	19,000 cfm, 36" SP Retrofit wheel, 66.5" dia 131 BHP at 1,750 rpm	Howden Fan Company
V-1, V-2, V-3, V-3	Man-Safe Wafer Damper and Expansion Joint	36" dia, man-safe, 0% leakage w/ seal air, electric operator	Effox, Inc.
N2-1	Nitrogen Supply	150 psig system Compressor, 100 cfm Tank, 3000 scf	Local
BB-1	Compressed Air Blowback System	100 psig system Compressor, 400 cfm	Local
I&C	Instrument and Control Upgrade		
Ductwork	Ductwork	100 linear feet 36" ID insulated steel duct 4 elbows 1 tee 1 cross Match transitions	Local
SC-1	Spare Candles	250	Filter Vendor 1

Table 5-3
Superior Graphite Plant Filter Retrofit CRADA
Detailed Estimate for Vendor 3 Design

CLIENT: U.S. DEPT. OF ENERGY
 PROJECT: SUPERIOR GRAPHITE PLANT FILTER RETROFIT
 DESCRIPTION: BARRIER FILTER INSTALLATION
 W. O. NO: 737324-00100

ESTIMATED : EVS
 CHECKED :
 REVISED : EVS
 REVISED : EVS

DATE : 26-Apr-00
 DATE :
 DATE : 29-Jun-00
 DATE : 14-Aug-00

FILE: C:\GRAPHITE\PLT\CR2\CLIENT\ALS

ITEM NO.	DESCRIPTION	QUANTITY UNIT	TOTAL MANHOURS	MATERIAL COST	LABOR COST	TOTAL COST
VENDOR 3 SCENARIO						
EQUIPMENT						
	BARRIER FILTER MODULE (F1-A, F1-B) w/ INSTRUME	2 EA	759	1,338,730	60,720	1,399,450
	1200 Candle at 5 FPM. 14.5' H x 20' L x 6' W					
	BARRIER FILTER PLATFORM	2 EA	238	12,820	19,040	31,860
	Grating, Handrail, Stairs					
	PNEUMATIC CONVEYOR	1 EA	112	8,800	8,960	17,760
	From Filter to Baghouse, 44					
	ID FAN UPGRADE (FN1-A, FN1-B) INCL HOUSING MC	2 EA	1,056	76,000	84,480	160,480
	19,000 CFM, 36" SP. Retrofit wheel, 66.5" dia, 131 BHP @ 1750 rpm					
	COMPRESSOR (N2-1), 100 CFM, 150 PSI w/ 6000 SCF	1 EA	48	20,330	3,840	24,170
	Nitrogen Supply					
	COMPRESSOR (BB-1), 400 CFM, 100 PSI w/ 1000 SCF	1 EA	66	49,650	5,280	54,930
	Compressed Air Blowback System					
	COMPRESSOR FOUNDATIONS	2 EA	81	880	6,480	7,360
	STRUCTURAL STEEL TO ELEVATE EQUIPMENT	1 ALW	880	80,000	70,400	150,400
	SUBTOTAL		3,240	1,587,210	259,200	1,846,410
DUCTWORK & DAMPERS						
DAMPERS & EXPANSION JOINTS						
	DAMPERS (V-1), 30" DIA., 0% LEAK, SEAL AIR, M.O.	1 EA	53	14,810	4,240	19,050
	DAMPERS (V-2,3,4), 36" DIA., 0% LEAK, SEAL AIR, M.O.	3 EA	177	49,550	14,160	63,710
	EXP. JOINTS, 36" DIA.	4 EA	106	11,250	8,480	19,730
	BUILDING DUCT PENETRATIONS	2 ALW	141	1,000	11,280	12,280
DUCT PLATE & STIFFENERS						
	FILTER MANIFOLD	2 EA	88	42,000	7,040	49,040
	DUCT, 3/16" X 36" DIA.	150 LF	317	18,750	25,360	44,110
	ELBOW, 3/16" X 36" DIA.	2 EA	38	2,250	3,040	5,290
	TEE, 3/16" X 36" DIA.	1 EA	25	1,500	2,000	3,500
	CROSS, 3/16" X 30" DIA.	1 EA	26	1,560	2,080	3,640
	DUCT SUPPORT STEEL (MISC HANGERS)	1,600 LBS	53	1,920	4,240	6,160
	INSULATION, CAL SIL W/JKT, 3" THICK	100 LF	440	9,170	35,200	44,370
	PAINT	432 SF	10	70	800	870
	SUBTOTAL		1,474	153,830	117,920	271,750
PIPING SYSTEMS						
NITROGEN PIPING						
	PIPE, 4" (COMPOSITE)	50 LF	65	630	5,200	5,830
	CONTROL VALVE, 4"	1 EA	13	3,500	1,040	4,540
	PAINT	1 ALW	4	30	320	350
AIR PIPING						
	MANIFOLD PIPE, 6" (COMPOSITE)	1 ALW	358	910	28,640	29,550
	PIPE, FLANGED, 2" X 12"	24 EA	106	410	8,480	8,890
	CONTROL VALVE, 2"	24 EA	66	8,400	5,280	13,680
	PAINT	1 ALW	4	30	320	350
	SUBTOTAL		616	13,910	49,280	63,190

Table 5-3 (Cont'd)
Superior Graphite Plant Filter Retrofit CRADA
Detailed Estimate for Vendor 3 Design

ELECTRICAL (ASSUMES EQUIPMENT TO BE POWERED IS WITHIN 100' OF SOURCE)

SWITCHGEAR LINE-UP	1 EA	70	200,000	5,600	205,600
MOTOR CONTROL CENTER	1 EA	18	8,000	1,440	9,440
RACEWAY & WIRING (POWER & CONTROL) FOR THE FOLLOWING:					
FILTER MODULE (DISTRIBUTION / PLC POWER)	1 ALW	23	230	1,840	2,070
SCREW CONVEYORS	1 ALW	85	900	6,800	7,700
DAMPERS, SEAL AIR FANS, & CONTROL VALVES	1 ALW	377	3,970	30,160	34,130
NITROGEN COMPRESSOR	1 ALW	54	760	4,320	5,080
BLOWBACK COMPRESSOR	1 ALW	83	1,830	6,640	8,470
SUBTOTAL		710	215,690	56,800	272,490

INSTRUMENTATION (CONTROL & INDICATION)

PROGRAMMABLE LOGIC CONTROLLER	1 LT	44	16,000	3,520	19,520
CONDUIT, 1 1/2" RGS (COMPOSITE)	750 LF	165	1,630	13,200	14,830
CABLE, 8 PR #18 TWSD	1,500 LF	30	920	2,400	3,320
TERMINATIONS	84 EA	18	60	1,440	1,500
SUBTOTAL		257	18,610	20,560	39,170

RELOCATIONS & MISCELLANEOUS

RELOCATE ATOMIZER RECYCLE TANK & PIPING	1 ALW	211		16,880	16,880
RELOCATE ATOMIZER RECYCLE PUMP & PIPING	1 ALW	141		11,280	11,280
RELOCATE MISCELLANEOUS INTERFERENCES	1 ALW	3,520	168,400	281,600	450,000
MODIFY EXISTING MONORAIL FOR RELOCATIONS	1 ALW	138		11,040	11,040
BUILDING EXTENSION W/FOUNDATION & UTILITIES	1 ALW		150,000		150,000
HAZMAT DISPOSAL	1 ALW		10,000		10,000
SUBTOTAL		4,010	328,400	320,800	649,200

SUBTOTAL DIRECT COSTS

10,307 \$ 2,317,650 \$ 824,560 \$ 3,142,210

ENGINEERING

\$ 471,330

CONTINGENCY (25%)

\$ 903,390

TOTAL DIRECT COSTS VENDOR 3 SCENARIO

\$ 4,516,930

SPARE CANDLES

\$ 81,000

OTHER SPARE PARTS

\$ 69,000

Table 5-4
Superior Graphite Plant Filter Retrofit CRADA
Equipment List for Vendor 3 Design

Identifier	Nomenclature	Description	Vendor/Source
F-1-A, F-1-B	Barrier Filter Module	1200 candles at 5 fpm. Module size 16' h, 21' l, 14' w Screw conveyor to outside unloading hopper	Filter Vendor 3
FN-1-A, FN-1-B	ID Fan Upgrade	19,000 cfm, 36" SP Retrofit wheel, 66.5" dia 131 BHP at 1,750 rpm	Howden Fan Company
V-1, V-2, V-3, V-3	Man-Safe Wafer Damper and Expansion Joint	36" dia, man-safe, 0% leakage w/ seal air, electric operator	Effox, Inc.
N2-1	Nitrogen Supply	150 psig system Compressor, 100 cfm Tank, 6000 scf	Local
BB-1	Compressed Air Blowback System	100 psig system Compressor, 400 cfm	Local
I&C	Instrument and Control Upgrade		
Ductwork	Ductwork	150 linear feet 36" ID insulated steel duct 4 elbows 1 tee 1 cross Match transitions	Local
SC-1	Spare Candles	360	Filter Vendor 3

6.0 CONCLUSIONS

- A barrier filter conceptual design was generated based on the Superior Graphite process conditions and physical layout. The barrier filter is expected to greatly reduce particulate carryover from the multiclones upstream of the scrubber. However, there is expected to be little SO₃ removed by the filter without the addition of separate absorbent material. Some test work has been done on injecting absorbents into barrier filters for SO₃ removal, but little if any commercial experience is available. Thus the degree to which a barrier filter upstream of the scrubber can enhance downstream stack opacity or reduce particulates in the downstream stack due to scrubber water carryover is difficult to determine (or unknown) and cannot be determined without full-scale operation.
- The Superior Graphite filter application will be unique due to its large size (designed for 40,000 acfm), the high percentage of carbon in the particulate (>75%), and the relatively high oxygen content (18%) when compared to flue gas.
- In response to an operational specification for the barrier filter, three vendors responded with an indication that they could provide filtration media. The DOE has also tested similar filters in much more severe conditions. Based on the vendor responses and DOE testing, it can be concluded that filter media are available to satisfy the Superior Graphite application.
- While guidance can be obtained from the design and operation of the Coventry Homefire Works filter, there are enough differences (coal versus coke as a carbon source, flue gas versus dilution gas, 30,000 acfm versus 40,000 acfm) that it would be prudent to run pilot plant tests on the Superior Graphite dust. The use of small multi-element pilot filters in a slipstream at the Hopkinsville plant can give valuable insights into the behavior of material being filtered and provides information necessary for the finalization of the design of full-size units. An objective of the pilot plant tests would be to verify for a particular filter media the face velocity that can be used while maintaining a stable pressure drop without dust re-entrainment or penetration. A second objective would be to determine the conditions necessary for preventing the combustion of solids on the filter elements in Superior Graphite's outlet gases.
- Space limitations are critical at Superior Graphite. Vendor 1's unit will fit in the existing bay. However, if pilot plant tests dictate a lower face velocity as was proposed by Vendor 3, an expansion of the bay will be needed, with the associated higher costs.

7.0 REFERENCES

- ¹ Beattie and Withers, "Applications of Low-Density Filters for Gas Cleaning at High Temperatures," Second International Symposium on Gas Cleaning at High Temperatures, University of Surrey, Guildford, UK on 27-29 September, 1993.
- ² Dennis, R. et al., "U.S. Department of Energy's High-Temperature and High Pressure Particulate Cleanup Program for Advanced Power Systems," Fourth International Symposium on Gas Cleaning at High Temperatures, University of Karlsruhe, Karlsruhe, Germany on 22-24 September, 1999.
- ³ "Assessment of Hot Gas Cleanup Systems for IGCC and PFBC Advanced Power Systems," Parsons Report No. 9607, DOE Contract No. DE-ACO1-94FE62747/ Task 18, January 1997.
- ⁴ Withers & Morson, "Ceramic Filtration of Black Smoke Emissions."
- ⁵ Davidson, M., et al., "Power System Development Facility: High Temperature, High Pressure Filter Systems in a Combustion Gas," Fourth International Symposium on Gas Cleaning at High Temperatures, University of Karlsruhe, Karlsruhe, Germany on 22-24 September, 1999.
- ⁶ Pontius, D. H., "Hot Gas Filtration Technical Issues," Southern Research Institute, Advanced Coal-Fired Power Systems '95 Review Meeting, June 1995.
- ⁷ Spain, J. D., "Properties of Ceramic Filters," Southern Research Institute, Advanced Coal Fired Power Systems '96 Review Meeting, July 16-18, 1996.
- ⁸ "Tidd Hot Gas Cleanup Program," Final Report by Ohio Power Company, DOE Contract DE-FC21-89MC26042, October 1995.
- ⁹ "Identification of Opportunities for the Use of Barrier Filters in Industrial Applications," Parsons Draft Report, DOE Contract No. DE-AC21-89MC25177/ Task 21, June 1998.
- ¹⁰ "Filter Out Black Smoke Emissions – The Result of a Good Practice Case Study at Cronite Precision Castings, Ltd.," 1997, ETSU Study No. GC68.
- ¹¹ Jones & Rogers, "The Evaluation of Low-Density Filters in a Boiler Flue Gas Clean-Up System," Second International Symposium on Gas Cleaning at High Temperatures, University of Surrey, Guildford, UK on 27-29 September, 1993.
- ¹² Sasatsu, H., "Performance of the Advanced Ceramic Tube Filter for the Wakamatsu 71 MWe PFBC Combined Cycle Power Plant," Symposium on High-Temperature Particulate Cleanup for Advanced Coal-Based Power Systems, April 20-23, 1998.
- ¹³ Personal Communication William Ellison, Ellison Consultants, December 1999.

¹⁴ Zievers, J. F. et al., "Simultaneous Hot Gas Desulfurization and Improved Filtration with Dry Scrubbing Using Waste Products," International Incineration Conference, May 12-16, 1997, Oakland, CA.