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WESTINGHOUSE ADVANCED PARTICLE FILTER SYSTEM

Authors:

T. E. Lippert
G. J. Bruck
Z. N. Sanjana
R. A. Newby

Contractor:

Westinghouse Electric Corporation
Science and Technology Center
1310 Beulah Road
Pittsburgh, Pennsylvania 15235

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Westinghouse Advanced Particle Filter System

CONTRACT INFORMATION

Contract Number	DE-FC21-89MC21023 DE-FC21-89MC26042 DE-FC21-90MC25140
Contractor	Westinghouse Electric Corporation Science & Technology Center 1310 Beulah Road Pittsburgh, PA 15235 (412) 256-2210
Contractor Project Manager	Thomas E. Lippert
Principal Investigators	Gerald J. Bruck Zal N. Sanjana Richard A. Newby
METC Project Manager	Richard A. Dennis
Period of Performance	October 1992 thru September 1997

Schedule and Milestones

Schedule and Milestones FY94

	S	O	N	D	J	F	M	A	M	J	J	A
Dynamic and Thermal Modeling	—	—	—	—	—	—						
Pilot Plant Testing												
AEP/Tidd	—	—	—	—	—	—	—	—	—	—	—	—
Karhula	—	—	—	—	—	—	—	—	—	—	—	
FW-Livingston	—	—	—								—	—
SCS/PSDF Design	—	—	—	—	—	—	—	—	—	—	—	—

OBJECTIVES

Integrated Gasification Combined Cycles (IGCC) and Pressurized Fluidized Bed Combustion (PFBC) are being developed and demonstrated for commercial, power generation application. Hot gas particulate filters are key components for the successful implementation of IGCC and PFBC in power generation gas turbine cycles. The objective of this work is to develop and qualify through analysis and testing a practical hot gas ceramic barrier filter system that meets the performance and operational requirements of PFBC and IGCC systems.

BACKGROUND INFORMATION

High temperature particulate filters are a key component in advanced, coal based gas turbine cycles (IGCC and PFBC) that are currently under development by DOE/METC for clean coal demonstration. In these applications the hot gas particulate filter protects the downstream heat exchanger and gas turbine components from particle fouling and erosion effects and cleans the gas to meet particulate emission requirements. Both PFBC and IGCC plants benefit because of lower cost downstream components, improved energy efficiency, lower maintenance and the elimination of additional and expensive flue gas treatment systems.

In IGCC systems, the hot gas particulate filter must operate in reducing gas conditions (i.e., presence of H_2, CH_4, CO), high system pressure (150 psi to 350 psi) and at operating temperatures usually determined by the method of sulfur removal, i.e., in bed, external or by cold gas scrubbing. Typically, these temperatures range around 1650°F (in-bed), 900 to 1200°F (external) and 1000°F to 500°F (cold scrubbing).

In gasification applications, cold scrubbing of the fuel gas has been demonstrated as effective in cleaning the fuel gas to meet turbine and environmental requirements. However, with this process, plant energy efficiency is reduced, and higher capital costs are incurred. Incorporating a hot particulate filter upstream of the scrubbing unit reduces heat exchanger costs and provides for dry ash handling.

Hot fuel gas cleaning concepts (in bed and external) have also been proposed that utilize reactive solid sorbents to remove gas phase sulfur and hot gas filters to collect the ash and sorbent particles. This approach in IGCC provides for highest energy efficiency and lowest cost of electricity.

IGCC systems may utilize air or oxygen blown entrained or fluid bed gasifiers. Specific operating conditions of the hot gas particulate filter will vary depending on these choices. In general, hot gas filter pilot plant test experience suggests that gasifier ash/char is noncohesive with relatively high flow resistance. Thus, the potential for fines reentrainment and high filter pressure drop are reduced by selecting a relatively low design filter operating face velocity (<5 ft/min). Since the filter treats only the fuel gas component of the total gas flow, the choice of a low filter face velocity does not adversely impact economics. Typically, for a 100 MW_e IGCC system, the filter is required to treat only 6000 to 12,000 acfm, depending if the gasifier is oxygen or air blown. Inlet dust loadings may also vary widely, ranging from <1000 ppmw to 10,000 ppmw.

Bubbling bed PFBC technology is currently being demonstrated at commercial scale. Two PFBC units are located in Sweden (Stockholm Energi, Vartan Plant), another one at the Endesa's Escatron Plant in Spain and one in the United States at the American Electric Power's (AEP) Tidd Plant located in Brilliant, Ohio. The Tidd PFBC is a 70 MW_e demonstration plant awarded through the Round 1 U.S. DOE Clean Coal Technology Demonstration Program. Currently, all four plants utilize high efficiency cyclones to remove greater than 95% of the ash and a ruggedized gas turbine to tolerate ash carried over from the upstream cyclones. Economic and performance improvements in these first generation type PFBC plants can be realized with the application of hot gas particulate filters. Both the secondary cyclone(s) and stack gas ESP(s) could be eliminated saving costs and providing lower system pressure losses. The cleaner gas (basically ash free) provided with the hot gas filter, also permits a wider selection of gas turbines with potentially higher performance.

For these bubbling bed PFBC applications, the hot gas filter must operate at temperatures of 1580°F and system pressures of 175 psia (conditions typical of the Tidd PFBC plant). Inlet dust loadings to the filter are estimated to be about 500 to 1000 ppm with mass mean particle diameters ranging from 1.5 to 3 μm. For commercial applications typical of the 70 MW_e Tidd PFBC demonstration unit, the filter must treat up to 56,600 acfm of gas flow. Scaleup to about 320 MW_e would require filtering over 160,000 acfm gas flow. For these commercial scale systems, multiple filter vessels are required. Thus, the filter design should be modular for scaling..

An alternative to the bubbling bed PFBC is the circulating bed concept. In this process the hot gas filter will in general be exposed to higher operating temperatures (1650°F) and higher (factor of 10 or more) particle loading. Although the inlet particle loading is high, it contains a significantly coarser fraction (mass mean generally >15 μm) which helps mitigate the effect of the higher mass loading. For a 75 MW_e commercial scale circulating bed PFBC plant, gas flow to the filter is approximately 70,000 acfm. At this scale, multiple vessels with modular filter subassemblies are required.

Second generation (or advanced) PFBC is being developed and planned for demonstration and commercialization. In this plant, higher (than first generation PFBC) turbine inlet temperatures are achieved by partially devolatilizing the coal in a carbonizer unit producing a fuel gas. The char produced is transferred and burned in a circulating PFBC unit with high excess air. The hot (1600°F) vitiated air produced is used to combust the hot fuel gas to raise the combustion gas temperature to as high as 2350°F (Robertson, et al., 1989). With second generation PFBC, two hot gas filters are required. One filter is used to collect the ash and char material carried over from the carbonizer unit with the hot fuel gas. The second filter is used to remove ash and sorbent particles carried over with the hot vitiated air leaving the circulating pressurized fluidized bed combustor (CPFBC). Both filter units are required to operate at high temperatures (1200 to 1600°F) and high particle loading. The fuel gas filter will operate in reducing gas while the CPFBC filter operates in oxidizing conditions. A 95 MW_e second generation PFBC demonstration plant requires a hot fuel gas flow to its filter of about 8000 acfm and hot vitiated air flow to its filter of approximately 64,000 acfm.

Westinghouse is currently evaluating candle and cross flow filter devices in subpilot and pilot scale PFBC facilities. These units are designed and operated to support the scaleup of these filters to commercial scale. Table 1 identifies the subpilot and pilot scale facilities that are currently operating (or plan to operate) with a ceramic barrier filter test system supplied by Westinghouse.

Foster Wheeler Advanced PFBC Facility

This testing is taking place at the Foster Wheeler Development Corporation (FWDC) pilot plant facility located at the John Blizard Research Center in Livingston, New Jersey. The second-generation PFBC development is divided into three phases. The first phase, already completed, developed a conceptual design of the commercial scale plant and identified R&D needs (Robertson et al., 1989). The second phase, completed in 1993, involved separate subscale pilot tests of the carbonizer/filter and circulating fluid bed combustor/filter components. The carbonizer/ filter testing was initiated in June 1992 and completed in September (Newby et al., 1993). Following this test program, the facility was modified for CPFBC operation, utilizing the candle filter unit. Shakedown tests on the combustor/filter components were initiated in

February 1993. Initial results from this testing have been reported (Lippert et al., 1993). A brief summary of the final test run made in the Phase II activity is reported herein. In phase three of the project, an integrated second generation PFBC pilot plant facility is being constructed and operated. The integrated facility includes both carbonizer and combustor filter units. This testing is scheduled to begin in June 1994.

Advanced Particle Filter Hot Gas Filter Slipstream (AEP/APF)

In August 1989 a cooperative agreement was signed between Ohio Power Company, through its agent, the American Electric Power (AEP) Service Corporation and the U.S. DOE to assess the readiness and economic viability of high temperature and high pressure (HTHP) particulate filter systems for PFBC. The test facility is a one-seventh (1/7) slipstream taken from the Tidd 70 MW (electric) PFBC Clean Coal Demonstration Plant located in Brilliant, Ohio (Mudd et al., 1992). Results of this testing are reported in a companion paper.

Ahlstrom PCFB Facility

Ahlstrom Pyropower has built a 10 MW (thermal) pressurized circulating fluidized bed combustor (PCFB) - ceramic barrier filter test facility located in Karhula, Finland. Through the AEP-PFBC hot gas cleanup cooperative agreement, the U.S. DOE/METC, AEP, Pyropower, EPRI and Westinghouse have embarked on a program to test the Westinghouse candle filter system under PCFB conditions. Results of this work are reported in a companion paper.

Power System Development Facility (PSDF)

Southern Company Services, under a DOE Cooperative Agreement (DE-FC21-90MC25140), is designing and constructing a Power Systems Development Facility that is intended to test and evaluate advanced coal based power generation systems and components. One test module is a 4 MW_e, Advanced Pressurized Fluidized Bed Combustion (APFBC) System including hot gas filters and gas turbine components. A second test module is a dedicated hot gas filter test leg consisting of the M. W. Kellogg transport technology for pressurized combustion and gasification to provide either an oxidizing or reducing gas environment. The full description of the PSDF is given in a companion paper. Westinghouse is providing two hot gas filters for installation and operation at the PSDF. One filter is intended for the combustor leg of the APFBC module. The second filter will be installed on the M. W. Kellogg transport reactor module.

PROJECT DESCRIPTION

Westinghouse is developing a high temperature particulate filter system for application in IGCC and PFBC, advanced power generation systems.

The Westinghouse hot gas filter design, shown in Figure 1, consists of stacked arrays of filter elements supported from a common tubesheet structure. In this design, the arrays are formed by attaching individual candle elements (Item 1) to a common plenum section (Item 2). All the dirty gas filtered through the candles comprising this single array is collected in the common plenum section and discharged through a pipe to the clean side of the tubesheet structure. Each array of filter elements is cleaned from a single pulse nozzle source. The individual plenum assemblies (or arrays) are stacked vertically from a common support structure (pipe), forming a filter cluster (Item 3). The individual clusters are supported from a common, high alloy tubesheet structure and expansion assembly (Item 4) that spans the pressure vessel and divides the vessel into its "clean" and "dirty" gas sides. Each cluster attaches to the tubesheet structure by a specially designed split ring assembly. The cluster is free to grow down at temperatures. The plenum discharge pipes ducting the filtered gas to the clean gas side of the tubesheet structure are contained within the cluster support pipe and terminate at the tubesheet. Each discharge pipe contains an eductor section. Separate pulse nozzles are positioned over each eductor section. The eductors assist pulse cleaning. During cleaning, the pulse gas is contained within and ducted down the discharge pipe and pressurizes the respective plenum section.

The plenum assembly and cluster (stacked plenums) form the basic modules needed for constructing large filter systems indicative of PFBC requirements. The scaleup approach is:

- Increasing plenum diameter (more filter elements per array)
- Increasing the number of plenums per cluster
- Increasing the vessel diameter to hold more clusters

In general, vessel diameter will be limited by the tubesheet structure and desire to shop fabricate the vessel. Larger PFBC plants would utilize multiple vessels.

The pulse gas used to clean the filters is provided from a pressurized source and delivered and controlled through a series of pipes and valves that comprise the pulse delivery subsystem. The key operating component is the fast acting solenoid valve that controls the pulse action. Figure 2 shows a simplified schematic of a single back pulse module. The module consists of a pressurized gas source, the pulse gas control function and the pulse gas distribution manifold. The cleaning pulse is initiated by first selecting and opening (through the control logic) one of the pneumatic activated ball valves on the pulse gas distribution manifold. The control solenoid valve is then activated allowing a short, high pressure pulse to travel through the opened ball valve and discharge through the pulse nozzle. High reliability and maintainability of this system is obtained by providing a redundant pulse gas control leg and associated isolation valves that allow on-line maintenance. The control logic is developed to automatically switch to the redundant line should a failure signal be received. Control of the pulse cleaning system will be based on either a timing sequence or filter pressure drop signal. The practical operation of this system has been demonstrated in the Tidd PFBC 10 MW_e hot gas filter slipstream.

This paper updates the assessment of the Westinghouse hot gas filter design based on ongoing testing and analysis. Results are summarized from recent computational fluid dynamics modeling of the plenum flow during back pulse, analysis of candle stressing under cleaning and process transient conditions and testing and analysis to evaluate potential flow induced candle vibration.

RESULTS

Computational Fluid Dynamics Modeling. A transient flow analysis was conducted to evaluate the flow conditions within the clean gas plenum section during a pulse cleaning event. The objective of the analysis was to determine the time when the pressure drop (given criteria) across the ash cake of each candle (during cleaning) was sufficient to remove the cake deposit. Also of interest is how the flow field is affected after the first candle is cleaned. A fifty-two (52) candle element plenum array was chosen for analysis. Computations were carried out using a general purpose computational fluid dynamics code. The symmetry of the flow field permitted solution in only half the domain. The major physical features of the candle/plenum arrangement are illustrated in Figure 1. The flow solution was three-dimensional and included the effects of compressibility and turbulence. Figure 3 shows the three dimensional CFD model. For this initial analysis, it was assumed the dust cake to be uniform and that cleaning of any single candle was uniform over its length.

Results of the analysis show all 52 candles (considering symmetry) are cleaned within a 48.4 to 49.0 ms after start of the pulse cleaning event. Table 2 shows the sequence of candle element cleaning. It was found that the velocity and temperature fields did not vary significantly in the time interval when the candles are cleaned. The flow field is not affected in a manner that would disrupt the cleaning of the other candles and that the candles are all cleaned at relatively the same time. Additional analysis is being considered to evaluate effects of nonuniform candle cleaning, nonuniform cleaning between candles, assumptions on ash properties and impact of broken candles.

Flow Induced Vibrations. The Westinghouse hot gas filter design utilizes free hanging candles fixed at one end to a metal plenum section. The possibility of damaging flow included vibration in the candle element caused by either normal gas filtration or pulse cleaning has been evaluated. The natural frequencies of the candle and mounting system were calculated and measured. The measurement was conducted by fastening accelerometers to the end of one of the candle elements mounted in the Westinghouse filter unit installed at the AEP/Tidd PFBC plant. Experiments were performed by "bumping" the candle and recording response; including frequencies and damping characteristics. From this testing, the largest spikes on the power spectra occurred at 84.37 and 114.45 Hz. Results of finite element mode frequency analysis that modeled the candle/holder system confirmed the measured natural frequencies. Four potential flow included effects were evaluated; Vortex shedding, jet switching, circumferential skimming and turbulence, Table 3. Failure criteria for each mode was established and then compared to the estimated effect based on the filter flow conditions, geometry and natural frequency. The turbulence parameter was estimated based on the results of computational fluid modeling done for one specific installation and flow arrangement. Results of the analysis show that the estimated effect of each flow mode fall significantly below the failure criteria. In general, therefore, flow induced vibration during the normal filtration process is not expected to be a significant factor in the mechanical durability of the candle filter system.

Following the "bump" tests on the accelerometer instrumented candle element in the Tidd filter unit, a series of cold back pulse tests were conducted to measure the candle acceleration and damping as a function of pulsing pressure. In these tests, as expected, the maximum acceleration (e.g., loading) increases with increased pulse tank pressure, Figure 4. The maximum measured acceleration was 0.7 g's at 700 psi under ambient conditions.

Since the g acceleration is expected to vary directly with modulus of elasticity, actual g loading under operating conditions are expected to be decreased. Calculations show that the reaction force at the candle caused by a 1-g loading results in a candle bending stress of less than 200 psi, well within the modulus of rupture limits of candidate candle materials.

Filter Thermal Stressing. Thermal stressing of the filter media occurs with cold backpulsing and whenever there is a sudden and rapid change in the process gas temperature. Such changes may be associated with plant startup, shutdown, plant trip or some unanticipated plant upset.

During filter cleaning, relatively large quantities of (cold) pulse gas flow through the porous ceramic wall causing rapid cooling within the ID wall region and high local tension stressing. Westinghouse calculations, given in Figure 5, show that local wall stresses are well in excess of the modulus of rupture (MOR) of current commercial candle filters. However, the ID wall stresses quickly, dissipate as the pulse gas is heated by the filter. As a result, microcracking of the ID surface may occur. The propensity of these microcracks to grow quickly and cause catastrophic filter failure is a property of the material (critical threshold stress intensity, K_{1c}). K_{1c} values are estimated by using a combination of two experimental techniques — the stressing rate dependence of strength and interrupted static fatigue tests.

Accelerated pulse cycling tests are currently being conducted to identify microcracking and confirm the integrity of candle elements.

Process thermal transients generally last several minutes or longer, subjecting the full filter body to temperature change. Pilot plant testing has shown that process thermal transients may range from <±10°C/min to over ±100°C/min. Thermal process transients that cycle, i.e., first increase temperature then decrease temperature, even through relatively low in magnitude, cause the filter body (from OD to ID) to cycle between tension and compression stressing, Figure 6. Such conditions may cause pre-existing flaws or cracks to grow, causing catastrophic failure of the filter element. Although large demonstration and commercial PFBC and IGCC plants are expected to be well controlled and process upsets minimized, tolerance to process thermal transients is a primary requirement of any filter material.

Pilot Plant Testing - Foster Wheeler APFB. The Phase II APFB pilot testing was completed in early December 1993. Filter testing has included separate operation on both the carbonizer and circulating pressurized fluid bed (CPFB) units (Lippert et al., 1993). The same 22-element candle filter unit was utilized for both the carbonizer and CPFB testing, Figure 7. The CPFB testing included a significant shakedown period (approximately 400 hours, representing nine different test runs) to evaluate CPFB operation and control. During this period the CPFB was tested on both coke and coal and the filter was exposed to severe upset events and process conditions that would vary widely. Candle breakage was incurred in some of the shakedown runs.

The final CPFB test run, following shakedown in the Phase II program, included a 180 hour continuous test period in which the CPFB and filter operated under char and coal fired conditions, Table 4. In this test, the filter was configured with 14 candle elements to operate at a face velocity of about 7.8 ft/min. the filter inlet dust loading ranged from about 1000 ppmw to 40,000 ppmw (depending on coal/char feedstock). Filter operating pressure drop was stable throughout the test run. The CPFB operated smoothly and without major upset. Inspection of the filter following completion of the test run showed the 14 candle element to be undamaged. No indication of dust leaks to the clean side could be identified. The residual filter cake was relatively uniform in appearance and did not show any crusty sublayer of sodium or potassium sulfate eutectic that had been experienced in one of the earlier shakedown runs.

Following the Phase II component testing, Foster Wheeler has now reconfigured the pilot plant to include integrated carbonizer and CPFB operation. The Westinghouse Phase II candle filter unit will be integrated with the carbonizer. A second hot gas candle filter unit has been designed and supplied for the CPFB. Table 5 summarizes the design and expected operating conditions for the two Westinghouse filter units. Phase II operation is expected to be initiated in late June or early July, 1994.

SCS/PSDF - Hot Gas Filters. Westinghouse is designing two hot gas particle control devices (PCD) for installation at the Southern Company Services Power System Development Facility located in Wilsonville, Alabama. Table 1 summarizes the basis for the two PCD designs. PCD 352 will be installed and integrated with the Foster Wheeler circulating PFBC unit. The filer is designed to utilize candle filter elements. Operating experience gained from the Karhula PCFB and Tidd PFBC filter testing have been factored into the PCD 352 design. Improvements include increased spacing between the candle elements and plenum pipe support structure, redesign of the plenum dust shields to enlarge and improve the path for ash discharge; recessing the candle filter holders into the clean gas plenum sections thus eliminating the region where dust can bridge and form clumps that ultimately can break off and get trapped between the candle elements. A steeper cone angle and large outlet flange are also employed in the vessel ash hopper region to promote ash discharge. The PCD 352 is scheduled to be delivered to the PSDF in the first quarter of 1995.

The PCD 301 unit will be initially installed and operated on the M. W. Kellogg transport reactor test module. The PCD 301 is designed to interchange the test cluster to accommodate a variety of filter types including:

- Advanced Candles
- Cross Flow
- CeraMem Axial Cross Flow
- Ceramic Bags

FUTURE WORK

Continued testing of Westinghouse hot gas filter system is planned this summer at the Foster Wheeler APFBC pilot plant facility. Testing of the Advanced design PCD 301 and 352 at the SCS/PSDF is scheduled to be initiated in the second or third quarter in 1995. Results of these and other ongoing filter testing will be utilized to demonstrate and qualify the Westinghouse Advanced Particle Filter for Clean Coal and commercial application.

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Table 1. Hot Gas Filter Pilot Plant Test Facilities

	Advanced PFBC (Foster Wheeler)				Southern Companies Services Power Systems Development Facility	
	Carbonizer	Combustor	PFBC (AEP-Tidd)	PCFB Ahlstrom	APFB Foster Wheeler	Transport Reactor, MWK
Facility Size	2 MWt	1.2 MWt	10 MWe	10 MWt	4 MWe	2 MWt
Coal Feed	Dry	Dry	Paste	Paste	Dry	Dry
Operating Temperature	1400-1600°F	1400-1650°F	1300-1550°F	1500-1650°F	1650°F	1800°F
Operating Pressure	100 - 200 psi	100 - 200 psi	130 - 150 psi	130 - 150 psi	200 psi	350 psi
Gas	Reducing	Oxidizing	Oxidizing	Oxidizing	Oxidizing	Reducing (Oxidizing)
Gas Flow (Nominal)	120 acfm	750 acfm	7500 acfm	3100 acfm	6000 acfm	1000 acfm
Precleaning	None	None	Cyclone	None	Cyclone	Cyclone

Table 2. Candle Cleaning Times

Time (sec)	Candle Numbers
0.04844	4
0.04845	5
0.04847	6
0.04848	1
0.04850	7
0.04852	8
0.04853	9, 16, 20
0.04855	10, 17, 19
0.04857	11, 21, 22
0.04858	12, 18
0.04859	13
0.04861	14
0.04862	15
0.04873	3
0.04877	2
0.04880	27
0.04882	26
0.04886	25
0.04884	28
0.04893	24
0.04899	23

Table 3. Summary of Candle Flow Induced Vibration Evaluation

Flow Mode	Criteria		Estimated	Comment
Vortex Shedding	At Critical Frequency (84 Hz)		~0.34 Hz	0.34<<84 Hz No Issue
Jet Switching	u/fD ≥100		0.2	0.2<<100 No Issue
Circumferential Skimming	Velocity >590 ft/s		<<590 ft/sec	No Issue
Turbulence ($0.5\ m^2/sec^2$)	Work Energy From Turbulence	>Energy Lost in Damping	$W_T < 2\% W_D$	No Issue

Table 4. Summary of CPFB TR5 Test Run

Operating Temperature	1550°F (Nominal)
Pressure	100 to 130 psi
Face Velocity	7 to 8 ft/min
Baseline ΔP	25 - 30 in wg
Dust Loading	1000 to 40,000 ppmw
Test Hours	183

Table 5. Summary of Hot Gas Filter Design and Operating Conditions for Phase III APFBC Testing

PHASE 2 FILTER - CARBONIZER

- Design Gas Flow (acfm) - 120
- Number Candles: 14 (max. 22)
- Face Velocity (ft/min): 2 - 3
- Pressure (psig): 100 - 200
- Temperature (°F): 1400 - 1600
- Dust Loading (ppmw): 2,000 - 20,000

CPFB FILTER

- Design Gas Flow (actual = 750)
- Number Candles: 36 (max 48)
- Face Velocity (ft/min): 5 - 8
- Pressure (psig): 100 - 200
- Temperature (°F): 1400 - 1650
- Dust Loading (ppmw):

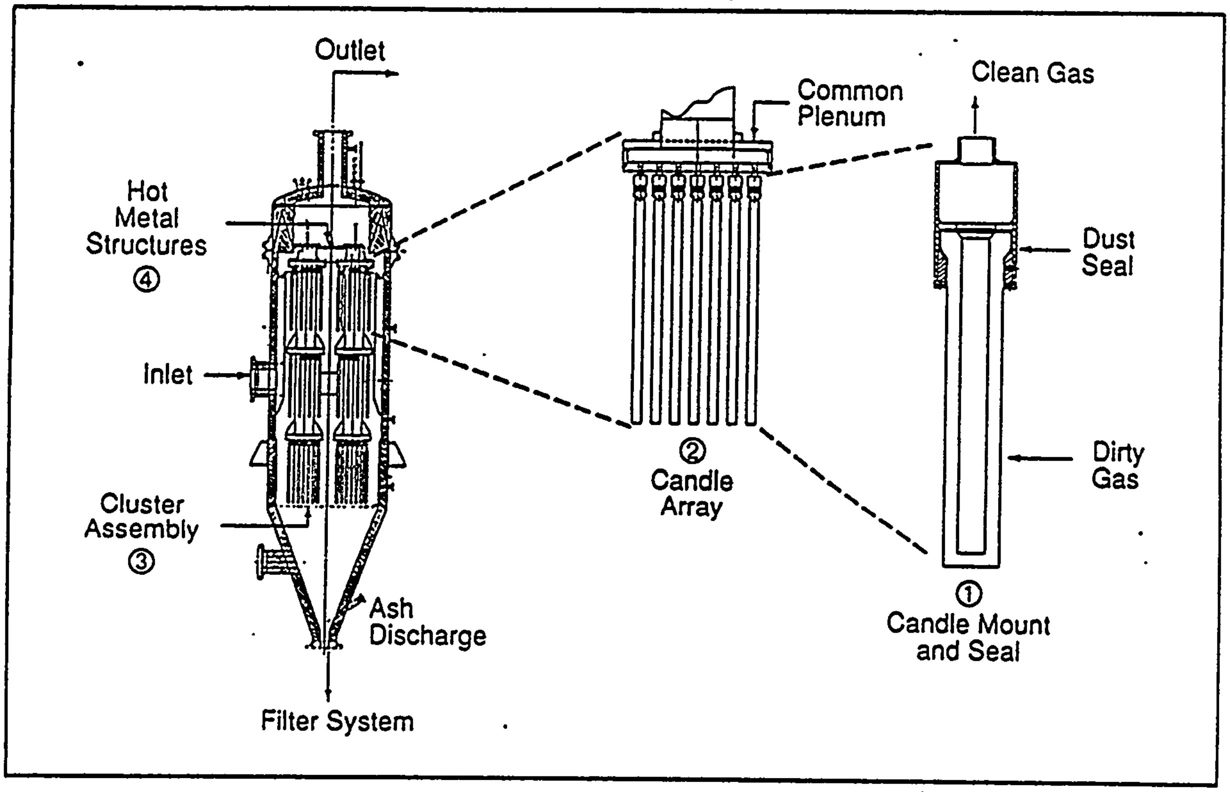

Figure 1. Hot Gas Cleaning Systems - Westinghouse Candle Filter System

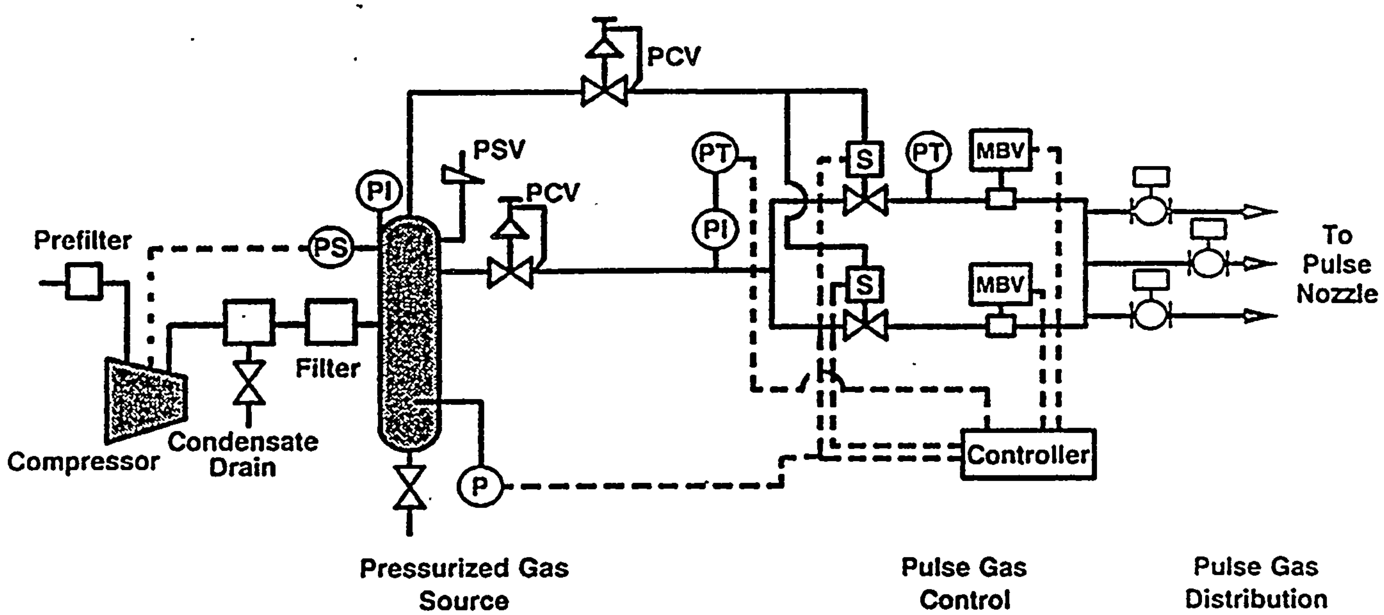

Figure 2. Pulse Gas System Schematic

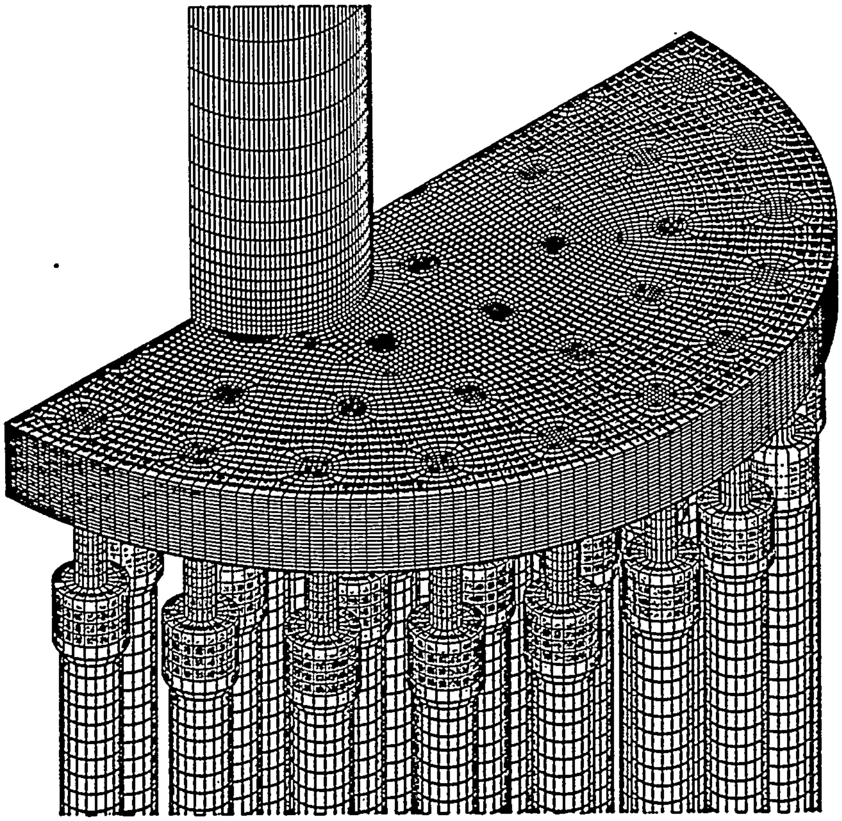

Figure 3. Westinghouse Candle Filter System

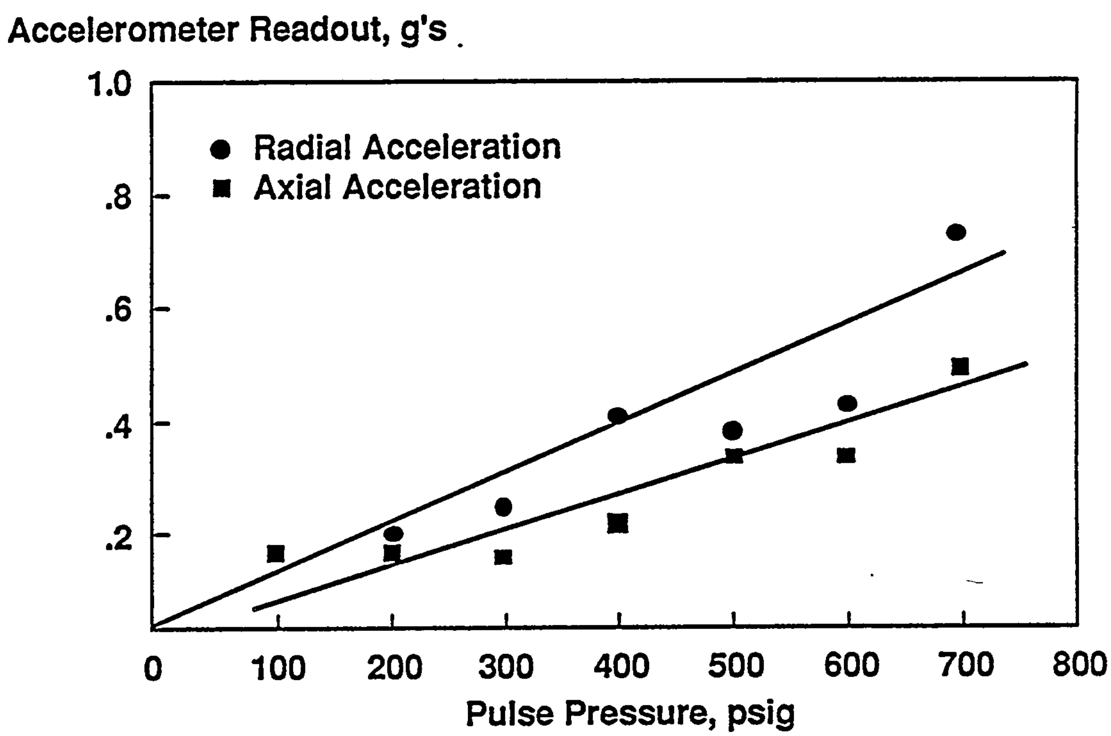

Figure 4. Pulse Induced Vibrations - Test Results

- High Candle ID Wall Tension Stresses - > MOR
- Potential ID Wall Damage (i.e. Microcracks)
- High Stressing Limited to 1 mm Wall Thickness
- Bulk of Filter Wall in Compression

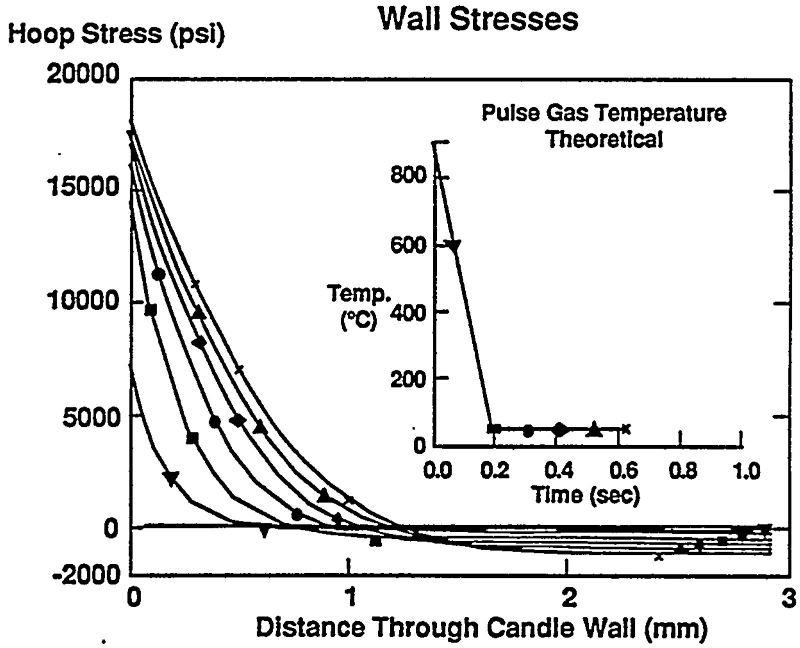

Figure 5. Filter Element Stressing - Cold Pulse Cleaning

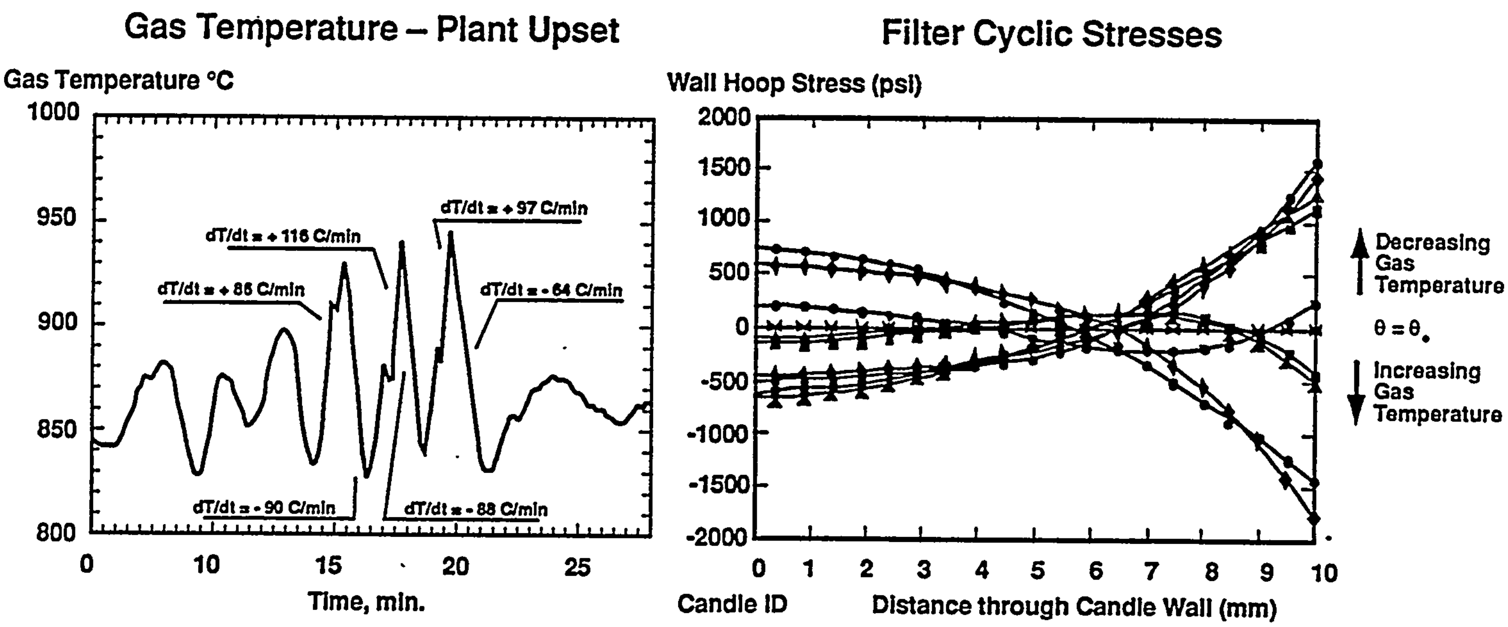

Figure 6. Filter Element Stressing - Process Transients

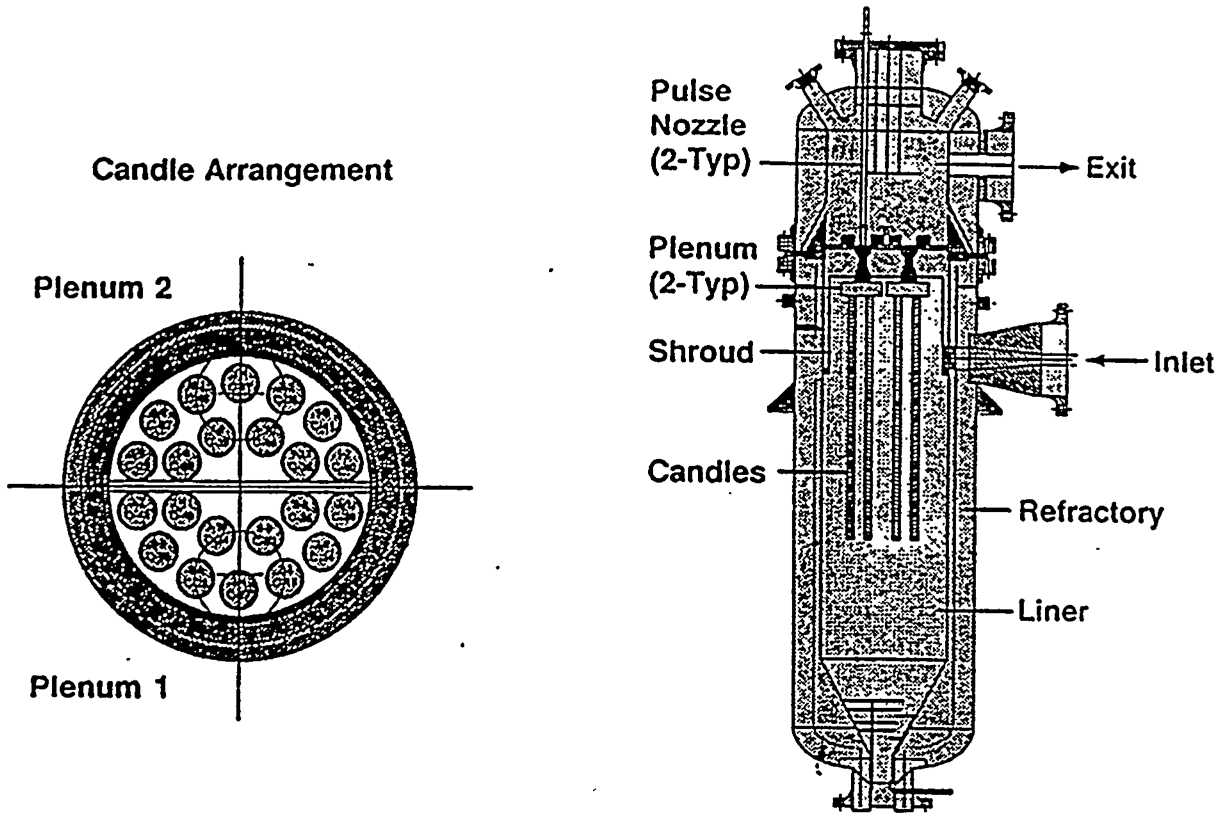

Figure 7. Schematic of 22-Element Candle Filter Installation