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TESTING AND VERIFICATION OF GRANULAR BED
FILTERS FOR THE REMOVAL OF PARTICULATE
AND ALKALIS

Eleventh Quarterly Project Report for the Period
April 1—June 30, 1983

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By
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ABSTRACT

The Westinghouse Electric Corporation with Ducon, Inc. and Burns and Roe, Inc. are conducting a test and evaluation program of a Granular Bed Filter (GBF) for gas cleaning applications in pressurized-fluidized bed combustion processes. This work is funded by DOE PRDA for Exploratory Research, Development, Testing and Evaluation of Systems or Devices for Hot Gas Clean-up.

This report describes the status of the testing of the subpilot scale GBF unit under simulated Pressurized-Fluidized Bed Combustion (PFBC) conditions through Phase IV and the design of a bench scale, single bed cylindrical element that will be utilized in Test Phase V.

1. INTRODUCTION

The Westinghouse Electric Corporation with Ducon, Inc. and Burns and Roe, Inc. are conducting a program to test and evaluate the Ducon granular-bed filter (GBF) for gas cleaning applications in Pressurized-Fluidized Bed Combustion (PFBC) Power Plants. The granular bed filter system may serve to remove from the gas stream both particulate and alkali metal compounds.

Figure 1-1 shows a schematic diagram of one element of the subpilot-scale Ducon granular bed filter. The element shown consists of four parallel operating filter compartments. Each compartment contains a granular filter-bed through which the ash and dust-laden gas pass (Figure 1-1a), depositing the ash and dust particles on the surface of the filter media. With increasing deposits of the particulates, the system pressure drop increases until a point is reached when it is no longer practical or economical to operate. The GBF system is then cleaned by sequentially backflushing each element (Figures 1-1b). For this purpose, a backflush motive air is introduced into an eductor at the outlet (clean air side) of a filter element. The motive air passes through the eductor (inducing additional clean gas from the clean-air plenum) and into the GBF element housing, up through each filter bed at a velocity and rate sufficient to gently fluidize each bed and dislodge the accumulated ash and dust material. The dislodged ash is elutriated and expelled from the element by passing back through the inlet opening provided at the top of each compartment. Figure 1-1 shows a four-bed element. Commercial scale GBF systems could consist of multiple elements each comprised of ten, twelve, or more parallel operating beds. An alternative design that uses a single bed, cylindrical element configuration has also been tested. This design is schematically illustrated in Figure 1-2.

FIG. 1 - SHALLOW BED - GBF CONCEPT

GBF ELEMENT - FILTRATION MODE

GBF ELEMENT - CLEANING MODE

Fig. 1-1 - Schematic representation of Ducon GBF element

Fig. 1-2 — Schematic of single-bed cylindrical GBF element

The major technical objectives of this work are:

1. The design and testing of a subpilot scale, multi-element (6) GBF to operate to temperatures of 900°C (1650°F) and pressures to 16 atm., at approximately 500 acfm.
2. Test and analysis to define the design approach and filter operation to accomplish alkali removal in PFBC.
3. The performance, economic and technical evaluation of a GBF hot gas clean-up system as it would be integrated in PFBC power plant conceptual designs.

The work reported covers the period April 1, 1983 through June 30, 1983. Prior work on this contract is documented in References 1 through 10.

2. TASK 1.1 - DEFINITION AND PRELIMINARY EVALUATION OF PFBC
PLANT CONCEPTS AND HOT GAS CLEAN-UP REQUIREMENTS

A draft copy of the reference PFBC system description write-up has been prepared by Burns and Roe. The report covers the overall plant descriptions, performance and costs.

In this study, three existing PFBC plant designs were modified to conform to the overall criterion and assumptions set forth in this study,¹ and to include a GBF for hot gas particulate clean-up and a fixed granular bed for alkali control. The specification of each plant design has included the following considerations:

1. Mass and energy balance
2. Overall plant performance
3. Sketch of plant layout
4. Estimate of plant costs
5. Conceptual design for GBF
6. Conceptual design for the alkali gettering bed
7. GBF and alkali bed operational characteristics
8. Estimate of turbine maintenance intervals

Submittal of the Burns and Roe report and its review and issue as a topical report completes the Task 1 work scope. A summary of the results from this study are provided in Reference 4.

3. TASK 1.2 - DESIGN AND TESTING OF THE SUBPILOT SCALE GRANULAR BED FILTER

This task encompasses the specification, design and testing of a multiple-element Ducon GBF subpilot scale unit. Testing has been conducted at the Westinghouse Synthetic Fuels Division's Hot Gas Test Facility at their Test and Development Center located at Madison, PA at the Westinghouse Waltz Mill site. Figure 3-1 shows a schematic diagram of the test facility in which redispersed fly ash (or other dusts) are fed at high temperature and pressure into the test vessel containing the GBF subpilot unit. Provisions for gas sampling are available on both the inlet and exit lines of the vessel. Figure 3-2 shows a photograph of the test facility. Figure 3-3 shows a schematic diagram of the instrumentation and controls typically used in the GBF test programs. Four test phases have been completed and reported, References 6 through 10.

During this report period, plans for a fifth test phase have been implemented. This work has included completing analysis of Test Phase IV and the design of a bench scale, single bed GBF test element. A summary of the GBF test programs to date and current test plans are presented.

3.1 Specification of the GBF Subpilot Unit Design

A preliminary report on the design and operating criteria for the GBF subpilot unit has been completed, Reference 1. The report provides the basis for specifying or calculating the major design and operating parameters for the GBF. This work was then updated to include an analysis of the design and operation of the eductor used in the GBF backflush system for high pressures and high temperatures, Reference 2. These studies have formed the design basis for the GBF subpilot test unit used in test Phases I, II, and III.

Operating Conditions

Pressure - Up to 150 psig (capability to 220 psig)

Temperature - 200 - 1600°F

Flow Rates - Up to 12 lb/s

Vessel - 56" Dia x 110" Length

Piping - 10" Sh. 80 with 6" Inconel Liners

Fig. 3-1—Schematic diagram of W-hot gas clean-up facility

Figure 3-2 - Hot Gas Clean-up Test Facility
(1982)

Figure 3-4 - Top view of GBF subpilot test unit showing the internal backflush piping lines, pressure tap leads and the applied thermal insulation on the inner portion of the support flange.

Figure 3-5 - View of GBF subpilot test unit being lifted to test facility pressure vessel. View shows applied thermal insulation around the outside of the support flange.

Figure 3-6 - Photograph of Assembled GBF Unit Readied for Testing

Summary Of GBF Tests – Test Conditions

	Phase I	Phase II	Phase III	Phase IV
GBF Configuration				
• Elements	Rectangular	Rectangular	Rectangular	Cylindrical (New)
• No Elements	6	6	6	6
• No. Beds/Element	4	4	1	1
• Total Beds	24	24	6	6
• Total Filter Area (ft ²)	12	12	3	10.8
Bed Media				
• Material	Alumina	Alumina	Sand	SS Wire Shot/Alumina
• Size (μm)	1370	1370	620	585/1370
• Bed Depth (in.)	1.75	1.5	3	1.5/1.5
Backflush Mode				
• Beds	Fluidized	Fluidized	Fluidized	Static
• Velocity (ft/s)	2.0	2.0	1.2	1.1
Nominal Operating Conditions				
Temperature (°F)	1600	1600	1500	1550
Pressure (psia)	165	165	125	125
Gas Flow (ACFM)	500	500	150	400

Summary Of GBF Tests - Results

	Phase I	Phase II	Phase III	Phase IV
Test Unit Configuration	Rectangular - 4 Beds/Element Alumina	Rectangular - 4 Beds/Element Alumina	Rectangular - 1 Bed/Element Sand	Cylindrical - 1 Bed/Element S.S. Shot/Alumina
Filter Face Velocity	40 To 50	40	50 75 100	45
Time At Conditions (Hrs)	50	50	71	50
Operating Cycles	103	90	282	140
Collection Efficiency (%)	98.8 To 99.4	98.9 To 80.8	99.2 98.5 96.0	99.8 To 80
Backflush Mode	On-Line	On-Line	Off-Line	On-Line

3.2 GBF Subpilot Unit Design and Fabrication

Design and fabrication of the original, rectangular, 6 element 24 bed GBF test unit was conducted by Ducon, Inc. Drawings and description of the test unit assembly were included in Reference 2.

The overall design basis for that unit is premised on a flow of 500 acfm at 1650°F (900°C) temperature and operation at 10 atm pressure with a maximum filter pressure drop during the filtration cycle of 5 psi. This filter pressure drop criteria actually translates to a maximum operating pressure differential of 9 psi that will occur when one element is backflushed (i.e., during the cleaning cycle). A redesign of filter element configuration to the single bed, cylindrical geometry illustrated in Figure 1-2 above and utilized in test Phase IV is described in Reference 9. Also included in Reference 9 is the basis and data for bed media selection and evaluation.

3.3 Test Program Status (Phases I, II, III, and IV)

The subpilot GBF test unit was delivered to the Westinghouse SFD-TDC facility site in September of 1981. Figures 3-4 and 3-5 show overall views of the test unit. Prior to initial hot gas testing, a series of cold-flow, ambient pressure tests were conducted to determine the flow vs pressure drop characteristics of the operating beds, observe the fluidization characteristics of the shallow beds, and to develop correlations between the measured eductor pressure drop and total mass flow through the eductor. These studies are reported in detail in Reference 5. In addition, hot gas testing of the unit has been conducted in three test phases. This work is reported in References 6 through 8. A fourth test phase has also been completed, Reference 10, that utilized the cylindrical, single bed element configuration. A description of the design is given in Reference 9, a photograph of the subpilot scale GBF test unit with the cylindrical element is shown in Figure 3.6. Tables 3-1 & 3-2 show the overall scope and accomplishments of test work through Phase IV.

In test Phase I, the GBF unit was operated under simulated PFBC conditions feeding reentrained ash obtained from the second stage, cyclone catch of the Curtiss Wright Technology Rig. Test conditions were 1600°F (874°C) nominal operating temperature at 165 psi (11 atm) pressure using a 1370 μ m tabular alumina as the bed media. The GBF

unit was operated for approximately 50 hours at conditions (cumulative time) and tested through about 103 operating cycles at a nominal filter face velocity of 40 ft/min (12 m/min). The significant accomplishments of this test phase (Phase I) have included:

- The integrated operation of the GBF test unit, its instrumentation and controls at PFBC conditions
- Showed that elutriated dust cake agglomerates would readily settle with no apparent crossover to other parallel operating elements
- That backflush times as low as 6 seconds could be achieved.

During testing, several mechanical design problems with the GBF unit were encountered that limited test data results and that necessitated subsequent repair. Two of the fiberfrax gaskets that provided dust seals between the elements and their respective eductor sections had failed providing a direct dust path to the clean-gas filter side and resulting in poor collection efficiency. Also, the tube couplings connecting the flexible backflush lines to the eductor had all loosened and some had detached. The ability to backflush and clean these filter elements was lost. Following this testing, the GBF unit was removed from the test facility vessel and the failed backflush lines and eductor-to-element dust seals repaired (see Reference 6).

A second series of tests (Phase II) have since been conducted. Results of this testing are reported in Reference 7 and showed the inability to maintain a uniform distribution of the backflush flow between the filter beds. This led to excessively high backflush flows through some of the filter beds, the possibility of bed media being elutriated and poor system performance. Subsequent cold flow testing showed significant differences between the flow resistance of the respective filter bed distributor plate and screen assemblies. Analysis of this data confirmed that the measured differences in flow resistance could indeed result in bed media elutriation in some of the filter beds.

A third test phase (Phase III) was conducted aimed at evaluating an alternative bed media (620 μ m sand) for improved dust collection

efficiencies. In addition, the test unit was modified by sealing-off all but one filter bed per element to circumvent the backflush flow problems encountered in Test Phase II. Results of this work are described in detail in Reference 8. The significant accomplishments of test Phase III are:

- At a nominal 50 (ft/min) filter face velocity, the overall test average collection efficiency was 99.2%. This performance level was averaged over approximately 230 operating cycles with inlet dust loadings that ranged to about 10,000 to 15,000 ppm with outlet loading measured from 13 ppm to 153 ppm.
- Increasing filter face velocity showed decreased collection efficiency. At 75 and 100 ft/min filter velocities, collection efficiencies were measured at 98.5% and 96.5% respectively.
- Most of the dust penetrating the filter unit does so during or immediately following the backflush cycle. Outlet dust samples taken only during the filtration portion of the operating cycle showed dust penetrations that were lower by nearly an order of magnitude compared to outlet dust samples taken over both filtration and cleaning cycle. This result suggests that overall collection efficiencies of 99.9% or greater could be achieved if backflushing could be done without fluidizing the filter media.
- Online cleaning of the test unit could not be accomplished because of high operating pressure drops that were associated with the eductor modifications necessitated by the reduced flow operation.
- Utilizing off-line cleaning, a stable baseline pressure drop cycle was achieved with the 620 μ m sand media and backflush velocities of about 1.2 ft/s.
- Post test analysis show some bed media loss ranging from about 18 to 34% of the initial change. Since tests were conducted over a relatively wide range of backflush flows, the bed media loss cannot be satisfactorily resolved.

In test Phase IV six cylindrical, single bed elements were utilized and each element loaded with a dual bed media comprising the 1370 μm alumina previously used in Test Phases I and II and a 584 μm (equivalent) stainless steel wire shot. Results of this testing is described in Reference 10.

In test Phase IV, the GBF test unit was operated for approximately 50 hours at gas temperatures of 1550°F, pressures from 80 to 125 psig, with a filter face velocity of about 45 ft/min and through 140 operating (filtration/cleaning) cycles. During the course of this testing, backflush flow conditions were varied and the test unit cleaned on-line. The maximum system pressure drop (Δp prior to cleaning) was varied from 15 in. H_2O to 30 in. H_2O with the filter unit operating at a stable baseline Δp (pressure drop after cleaning) of less than 10 in. H_2O . Stable operating cycles were maintained with online cleaning and with backflush velocities as low as 1.0 ft/sec. Because conditions changed in the bed and the backflush flow varied, it was impractical to maintain one backflush set point and the reverse flush static bed cleaning was not maintained as originally planned.

In the initial portion of the test run, overall collection efficiencies were measured that were in excess of 99.3% with outlet dust loadings that ranged from 7 to 40 ppm and filter inlet dust loadings from 2/40 to 4875 ppm. After about 14 test hours, there was a significant decrease in the performance of the filter unit. Inspection of the test unit showed that bed media had penetrated through the distributor to the clean gas side, and that substantial bed media had been lost exposing portions of the distributor plate assembly. Further inspection of the plates showed them to be distorted and physically separated from the screen. These observations account for the decreased filter performance and need to improve the mechanical design of the distributor plate assembly.

The shallow granular bed concept adapted to operate with a static bed reverse flush cleaning is a significant departure from the reverse flush fluidization cleaning approach. The inability to demonstrate improved

performance using the reverse flush static bed cleaning in test Phase IV because of recurring mechanical design problems with the distributor plate assembly has prompted a redirection of the test program approach towards a smaller, single bed test unit of modified design. Testing on this unit is planned for the bench scale hot gas test facility located at the Westinghouse R&D Center.

3.4 Bench Scale GBF Test Unit Design

A design for an 8 inch diameter, single element GBF unit has been completed. Drawings of the unit are shown in Figure 3-7 and 3-8. The unit is designed and sized to fit into and operate with the existing bench scale test facility pressure vessel and flow capability. Major features of the GBF design include:

- A cylindrical filter element 8 inch in diameter with an overall length of 14 inches
- A distributor plate assembly that is supported on a conical expansion ring that allows for thermal expansion
- Designing the distributor plate to provide a significant fraction of the total system pressure drop. This should ensure a uniform distribution of the backflush flow over the filter bed surface. This is accomplished by appropriately sizing the distributor plate orifices and covering the distributor plate with a fine mesh screen. The screen provides additional reduction in the open area of the distributor plate as well as preventing the bed media from falling through the plate perforations
- The screen overlaying the distributor plate is welded to the plate in a pattern that ties the screen around each orifice. This should help minimize the effect of any distortion that might tend to occur between plate and screen.

Figure 3-7 - Bench Scale GBF Assembly Arrangement

Figure 3-8 - Design of Eench Scale, Single Bed GBF Test Unit

Table 3-3 summarizes the key GBF design parameters and planned operating test conditions. Fabrication of the test unit should be completed by August with testing initiated on or about September.

Table 3-3

GBF DESIGN AND TEST OPERATING PARAMETERS

<u>Parameter</u>	<u>Nominal Values</u>
• Bed Area, in ²	40
• Bed Media (depth, in)	alumina (3.0) wire shot (1.0)
• Test Conditions	
• Temperature, °F	1600
• Pressure, psia	165
• Filter Velocity, ft/min	40
• Nominal Backflush Velocity, ft/s	1.0
• Operating Pressure Drop, in H ₂ O	
• Filtration	10-20
• Backflush	15-40
• Distributor Plate and Bed Media Design & Operating Parameters	
• Pressure Drop, in H ₂ O	14
• Minimum Fluidizing Velocity, ft/s	1.2
• Maximum Spoutable Bed Depth, in	2.0
• Open Area Fraction	0.012

4. TASK 1.3 - ALKALI METAL REMOVAL

Work on this task has been aimed at the evaluation and selection of possible alkali sorbents that could be used with the Granular Bed Filter system. Tests have been conducted on a number of candidate materials to measure their overall alkali uptake and the chemical kinetics between the alkali and sorbent. Results of this work have been reported (References 1 through 7) and the scope of the planned work completed. Additional alkali gettering work is still being carried through on the DOE contract DE-AC21-80MC16372 "High Temperature Removal of Alkali and Particulates in Pressurized Gasification Systems." The monitoring of this work will continue throughout the contract period and data applicable to the GBF concept will be incorporated into the final system evaluations.

5. TASK 1.4 - PFBC SYSTEM PERFORMANCE

A preliminary set of parametric studies have been conducted to evaluate specific GBF design and operating parameters with respect to their impact on the three PFBC reference plant concepts.³ The impact of the different GBF design and operating parameters is measured by the calculated reduction (or increase) in the net plant output relative to the same plant operating without the GBF. For a given PFBC concept, this basis provides a simple normalized comparison to evaluate the relative effects of selected parameters, and the relative sensitivity of varying one parameter over a range of conditions. Also, between plant concepts, the analysis has provided a relative basis for determining if a different set of GBF operating and design parameters are more appropriate for one PFBC concept over the next.

In addition, a preliminary set of economic trade-offs have been completed that compare the all-cyclone PFBC steam cooled and air cooled plants to the reference PFBC plants developed in Task 1.1. The all-cyclone plant description was developed under an independent Westinghouse study funded by ANL/DOE, Contract ANL 31-109-38-6308. For the purpose of the present study, an economic comparison is made between the costs for particulate gas clean-up between the two plants as a function of the operating characteristics of the GBF unit (face velocity), Reference 6. No system studies have been conducted this report period. Additional planned work in this task has been reduced in favor of increased GBF test work.

6. TASK 1.5 - COMMERCIAL SCALE GBF CONCEPTUAL DESIGN

Initial efforts scheduled in this task have been reported.³
Additional work on this task has been reduced in favor of Phase IV
and Phase V testing.

7. REFERENCES

1. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T1, (Quarterly Report for the Period October through December 1980), to be issued.
2. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T2, (Quarterly Report for the Period January through March 1981), to be issued.
3. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T3, (Quarterly Report for the Period April through July 1981), to be issued.
4. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T4, (Quarterly Report for the Period August through October 1981).
5. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T5, (Quarterly Report for the Period October 1981 through December 1981).
6. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T6, (Quarterly Report for the Period January through June 1982).
7. "Testing and Verification of Granular Bed Filters for Removal of Particulates and Alkalies," DOE/ET17093-T7 (Quarterly Report for the Period April through June 1982).
8. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T8 (Quarterly Report for the Period July through September 1982).
9. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T9 (Quarterly Report for the Period October 1982 through December 1982).
10. "Testing and Verification of Granular Bed Filters for Removal of Particulate and Alkalies," DOE/ET17093-T10 (Quarterly Report for the period January through March, 1983).