United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-79-112
May 1979

EPA

Extended Tests of Saffil Alumina Filter Media

Interagency Energy/Environment R&D Program Report

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EPA-600/7-79-112
May 1979

Extended Tests of Saffil Alumina Filter Media

by

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Contract No. 68-02-2611
Task No. 20
Program Element No. EHE624A

EPA Project Officer: Dennis C. Drehmel

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

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FORWARD

New methods of using coal in energy processes are being developed. These methods include pressurized fluidized bed combustion (PFBC) and gasification combined cycle (GCC) processes. These new technologies require development of hot gas cleaning devices to remove particulates from the process stream. This particulate control is required to protect equipment downstream of the combustor in the process as well as for protection of the environment. The economics of the process can be improved if a single device or system can accomplish both objectives. The Particulate Technology Branch of the Industrial Research Laboratory has taken a lead in development of hot gas cleaning systems through their support of investigative work in this area.

The work reported here is part of the EPA effort to support development of hot gas cleaning devices. This effort has involved an investigation at Acurex Corporation of ceramic fibers with respect to application in high temperature and pressure filtration.

PREFACE

Previous work carried out under EPA Contract 68-02-2169 and reported in EPA-600/7-78-194 examined the performance of a number of commercially available ceramic fiber materials with respect to their suitability for high temperature and pressure filtration. This earlier work demonstrated that filtration with ceramic fibers was feasible. SAFFIL alumina was identified as one of the most promising of the materials currently available for application in construction of HTHP filters.

This report presents the results of an effort to perform 200-hour endurance tests of filters constructed of SAFFIL alumina. Three such tests were completed, covering a range of filter media face velocity from 2.5 to 9 cm/sec. Tests were performed at nominally 815°C and 10 atm pressure using fly ash obtained from the EPA/Exxon Miniplant. This work was done in preparation of filter tests on a slipstream of gas from the EPA/Exxon Miniplant. Slipstream tests were conducted under EPA 68-02-2611, Task 25 and will be presented in a separate report.

SAFFIL™ is a registered trademark of Imperial Chemical Industries, Limited for inorganic fibers.

ABSTRACT

This research effort was performed with the objective of developing filter media performance data under simulated PFBC conditions for one ceramic filter media candidate. The media selected consisted of a low solidity fiber bed constructed using SAFFIL alumina ceramic fibers.

Dust feeding tests were performed at a nominal temperature of 800°C and 10 atm pressure using reintrained fly ash which had been collected at the EPA/Exxon Miniplant. Tests were performed at three filter media face velocities: 2.5, 4.8, and 9.0 cm/sec. Each test was performed for a duration of 200 hours.

Pressure drop and collection efficiency were determined as a function of time and as a function of filter face velocity. Off-line cleaning by reverse pulse was shown to be effective in maintaining low pressure drop -- <1.25 KPa after a cleaning cycle. Collection efficiency was high (>99.9 percent) and was maintained over the 200 hour test. Collection efficiency was also shown to be substantially independent of face velocity over the range tested. Outlet concentration was less than the most stringent requirements proposed for turbine applications (generally <1mg/Nm^3). Outlet concentration showed a trend towards lower values at higher filtration velocity. Mechanical durability was indicated in that none of the test filters appeared to have been damaged by the 200-hour tests with cleaning cycles occurring once every 10 minutes.

These tests have provided additional evidence that ceramic fibers can be utilized to develop successful high temperature filter media and Acurex recommends that additional work to develop ceramic filters should be performed.

This report was submitted in fulfillment of Contract No. 68-02-6811, Task 20 by Acurex Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from January 12, 1978 to December 30, 1978, and work was completed as of March 15, 1979.

CONTENTS

FIGURES

ACKNOWLEDGMENTS

Much of the data for this report was collected by Mr. Chris Chaney of Acurex. Mr. Robert Fulton of Acurex provided engineering support for the tests.

Dr. Dennis Drehmel was the EPA project officer and deserves special thanks for his continuing interest and support which was required to see the work through to a successful result.

SECTION 1

INTRODUCTION

The need for hot gas cleanup associated with the development of advanced coal utilization technology, including pressurized fluidized bed combustion (PFBC) and gasification combined cycle plants, has been apparent for several years. Current trends in PFBC technology development indicate there is a continuing hope that turbines can be adequately protected with particle removal from staged inertial separation devices. Military experience does not support this hope. Helicoper turbine engines have been fitted with small, high efficiency 2.5-cm diameter cyclone tube banks to extend service life to a moderately acceptable level, where dust loading is intermittent. The U.S. Army XM-1 Main Battle Tank is turbine powered and employs a barrier filter system with a cyclone tube bank precleaner. This system is capable of providing engine intake air as clean as that required of heavy duty diesel engines. In the world's most severe dust conditions (Yuma Proving Ground, Yuma, Arizona), dust loadings at the rear deck of a tracked vehicle are about 17 g/Nm^3. Dust loadings in excess of this are encountered in the exhaust of the PFBC.

E. F. Sverdrup of the Westinghouse Research and Development Center analytically determined the tolerance of large turbines to particulate loading (Reference 1). Sverdrup's calculations indicate that cleaning of turbine expansion gas to a level of 4.6 mg/Nm^3 (0.002 grains/SCF) -- with all particles larger than 6 μm removed -- is currently the best estimated level of cleanliness needed for turbines. This analysis resulted in a maximum blade erosion of 0.10 inch in 10,000 hours of operation. This level of cleanliness is approximately 80 times less than the exit loading expected from three cyclones in series. Filtration tests at Acurex have shown removal efficiencies resulting in a particulate exit loading considerably lower than that specified by Westinghouse.

Nearly every type of particulate removal device has been proposed for HTHP application, including acoustic agglomerators, molten salt scrubbers, varieties of cyclones, granular beds, HTHP electrostatic precipitators and ceramic filters. Professor E. Weber from the University of Essen has published a review paper entitled "Problems of Gas Purification Occurring in the Use of New Technologies for Power Generation" (Reference 2). In this paper, he concludes that gravity and momentum force separators will not adequately remove particles from HTHP gas streams and will, therefore, be used only as precleaners. He also states that the required degree of cleaning can be achieved using fabric filters, and points out that fibrous materials are available which can withstand the temperatures expected in PFBC applications.

Granular bed filters have been considered the best available option for HTHP particulate control. However, tests at the Exxon Miniplant have shown that many problems remain to be solved before achieving high efficiency and long life in these devices (Reference 3).

Many of the particle removal devices proposed for HTHP applications operate primarily through the mechanism of inertial impaction. These devices include all forms of cyclones, scrubbers and granular beds. Because gas viscosity increases with rising temperatures, performance of all inertial devices can be predicted to be worse at HTHP conditions than at room ambient conditions. Barrier filtration, on the other hand, is unique in that a theoretical basis exists to predict improved performance at high temperature and pressure conditions. This improvement results from using fine (3 μm) diameter ceramic fibers to construct the filter. Conventional filter media usually employ fibers of 10 to 20 μm in diameter. The fine diameter fibers increase the filter efficiency enough to overcome the adverse effects of increased temperature.

In August 1976, Acurex began an EPA-sponsored program to demonstrate the feasibility of employing available ceramic fibers in high temperature and pressure filtration. Under this 2-year contract the theory of barrier filtration was examined and a wide spectrum of ceramic papers, cloth and blanket felts were tested for filtration performance at room ambient conditions. A high temperature and pressure filter test rig was built. Promising media from room ambient tests were subjected to accelerated cleaning tests at HTHP conditions for 50,000 cleaning pulses. In addition, ceramic blanket materials were shown to offer the greatest promise for further development into high temperature filter application. During extended duration tests of 200 hours over a range of filter media face velocity (air-to-cloth ratio), SAFFIL alumina was judged to be the best commercially available material for filter application.

SECTION 2

SUMMARY AND CONCLUSIONS

Three filter elements were successfully tested for 200 hours each in a high temperature and pressure environment (800°C, 10 atm) while filtering injected fly ash. The tests were performed at filter face velocity up to 9 cm/sec. When tested under laboratory conditions, the low solidity ceramic fiber media achieved high collection efficiency (>99.9 percent), and was cleanable, maintaining a steady level of pressure drop (<2.5 kPa). It operated even in high dust loading conditions, and survived the 200-hour tests without apparent mechanical degradation.

This test series strongly supports the conclusion that available ceramic fibers can be successfully developed into filter media for high temperature and pressure application.

High efficiency fine particle collection results from the use of small fiber diameter (3 μm nominal) in the design of the filter media. The media's ability to withstand cleaning stresses results from both fine fiber diameter and low solidity. The individual fibers are not held tightly together, and because of their low mass do not exert large forces on each other. Filter cleaning is enhanced through the use of fine fibers and off-line cleaning. The high collection efficiency of the fine fibers results in collection of particles near the surface of the media. Off-line cleaning eliminates reintrainment of dust to the filter element being cleaned and to neighboring elements in the filter module taken off-line. This feature also allows the filtration cycle to be accomplished at high velocity because it is reintrainment which limits air-to-cloth ratio in currently available pulse filter systems. The ceramic components are not inherently expensive. High temperature/pressure filters will cost more than standard filters, but primarily because of the pressure vessels, insulation requirements and the use of corrosion resistent alloys. These factors are present in all the components of a PFBC system. Compared to the costs of these components, the filter media cost is expected to be acceptable.

SECTION 3

RECOMMENDATIONS

Testing of ceramic filters to date has been aimed at showing that these materials can be used for filtration purposes. This objective has been accomplished and it now seems clear that a practical high temperature filter can be developed. Protecting gas turbines from the products of coal combustion in a PFBC is a difficult task and Acurex recommends that work on filtration using ceramic fiber media be resumed as quickly as possible. Component development, performance optimization, and verification of long term durability all need to be addressed for HTHP applications.

Since ceramic filters are capable of suspending a dust cake having a large surface area across the gas stream, this dust cake may be doped with chemicals upstream of the filter. These chemicals have the potential to react with gaseous constituents in the stream and to capture or modify them. Thus, the high temperature filter has the potential of "dry scrubbing" undesireable components from the gas stream, and this capability should be fully investigated as well.

Furthermore, a high temperature filter in atmospheric pressure applications offers the potential of obtaining the particle collection benefits of filtration over a wider temperature range than is presently available. For example, heat recovery and subsequent energy savings may be enhanced with a high temperature filter. The size of such a device could be reduced because the need for dilution air will not be as great. This capability, coupled with operation at high filter face velocity and heat recovery, could offer fine particle control at a lower total cost than is presently possible in other applications. There are also many process applications where a high temperature filter could offer savings in energy, efficiency or product recovery.

SECTION 4

TEST SETUP

This section describes the test procedure used in performing the 200-hour dust feeding durability test. An earlier report (EPA-600/7-78-194) describes the filter media test rig.

Figure 1 shows a simplified schematic of the test setup, and Figure 2 provides a cross section of the filter test chamber. The actual piping is more complicated than shown because the test rig can also operate in a reverse flow mode. However, the essential flow paths are as shown. Primary air flow at 10 atm pressure is provided by a large compressor. This air is preheated by being forced through a preheater section and injected into the bottom of the test chamber. A second compressor provides high pressure air for pulse cleaning and for feeding dust into the test chamber. Cleaning pulses are introduced through a fast-acting solenoid valve located above the test chamber. After passing through the test filter, the cleaned gas flows through a heat exchanger section to be cooled prior to the removal of any particles which have penetrated the test filter. These penetrating particles are collected in the absolute filter. A solenoid operated valve located downstream of this point is used to stop forward flow of the primary gas for the cleaning cycle. A critical orifice is used to regulate the flowrate of gas for the test.

Dust feeding is accomplished by using a rotary table dust feeder mounted in a pressure vessel (see Figure 3). The dust feeder pressure vessel is maintained at a pressure greater than the test system pressure (about 1250 kPa). The exit tube for the dust feeder, located above the table groove, is passed through the preheater and connected to the test chamber. The dust injection tube is located so that dust is impacted against a heavy metal plate below the test filter element. This is done in an effort to redisperse the injected dust because excessive dust feeder pressures are required to pass the dust through a shock. Consequently, redispersion of the test dust was perhaps not as good as it could have been in an atmospheric pressure test.

Fly ash collected from the second stage cyclone (Run 67) at the EPA/Exxon Miniplant was used for all tests except those noted in the test descriptions in Section 5. This dust has an average particle size distribution of D_{50} = 19 μm, which is coarser than as-generated dust. Using redispersed fly ash instead of as-generated fly ash results in somewhat lower than expected operating pressure drop.

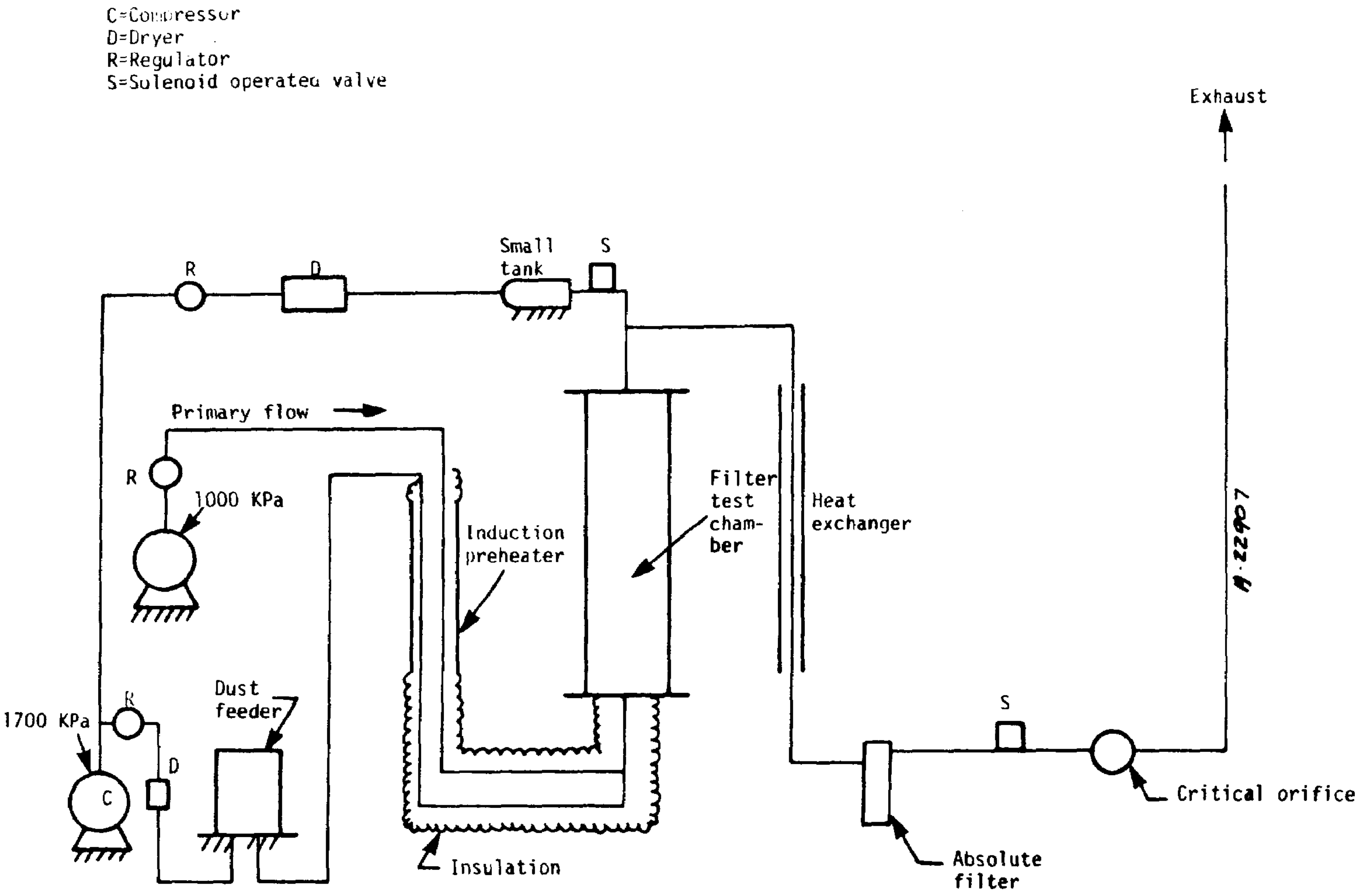

Figure 1. Simplified test schematic.

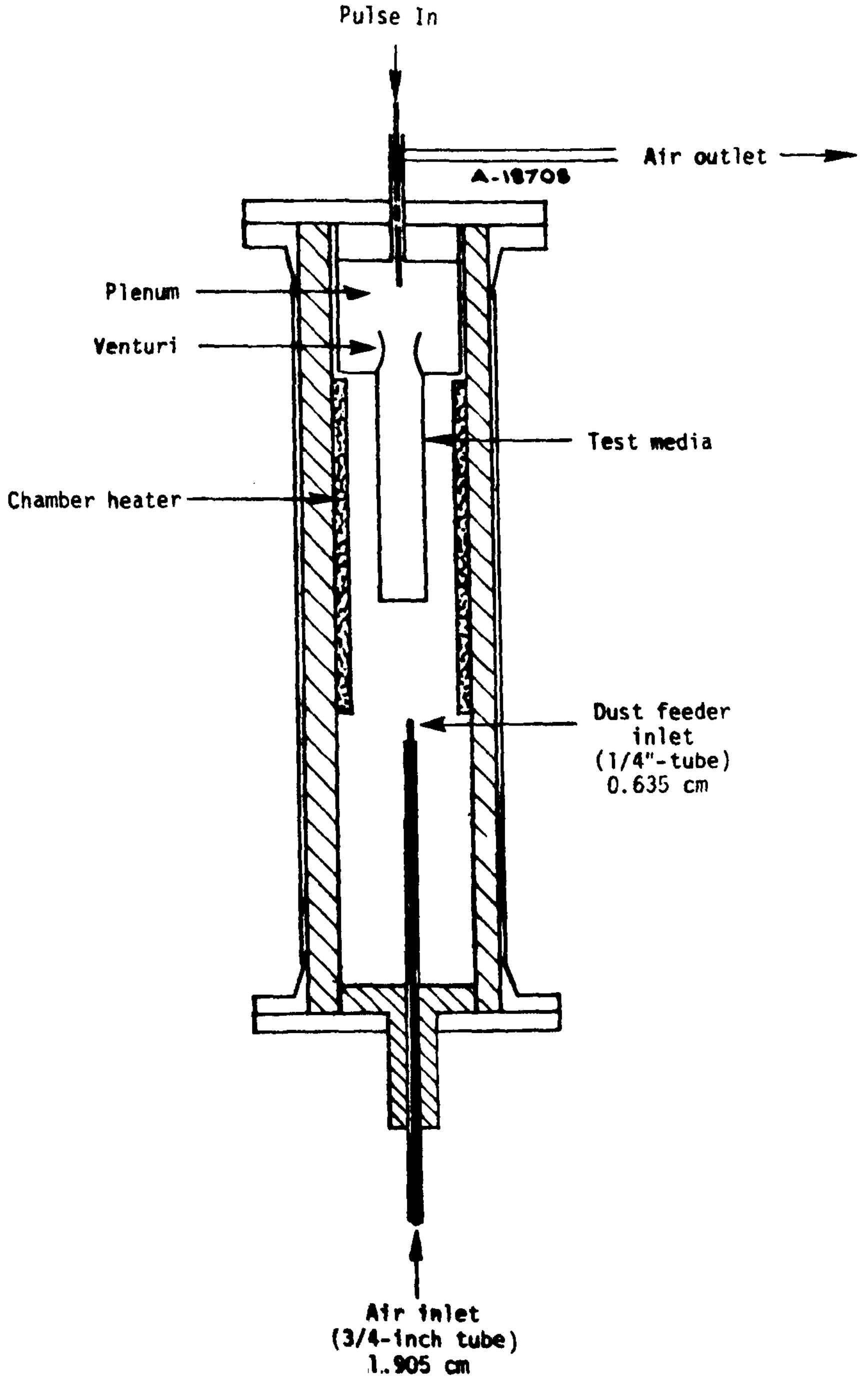

Figure 2. Test chamber cross section.

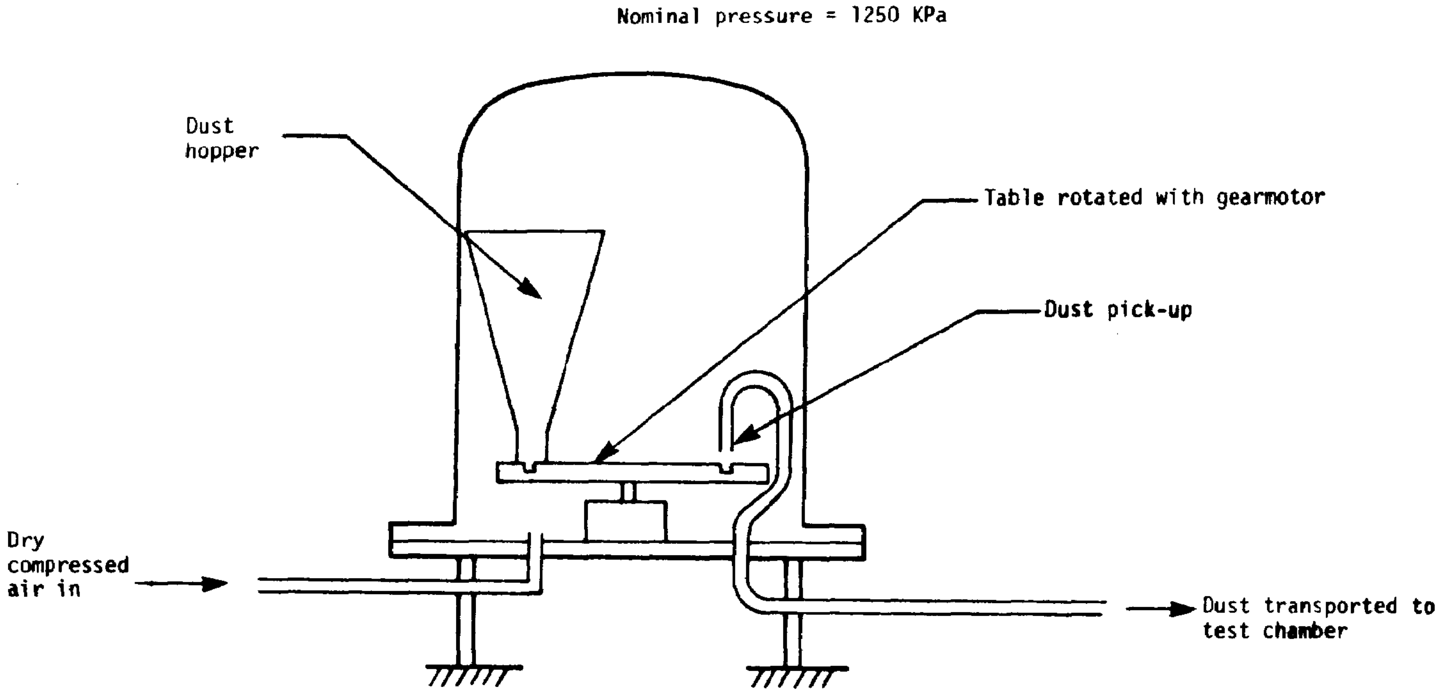

Figure 3. Dust feeder schematic cross section.

SECTION 5

TEST RESULTS

Section 5.1 presents a short review of theory and earlier test results. High temperature and pressure dust feeding test results are presented in Section 5.2.

5.1 BACKGROUND

Filtration Theory Review

The theory of barrier filtration has been presented in many sources. The method used in this program was based on work by Torgeson, Whitby and Iinoya for single fibers and fiber beds (Reference 4). The key finding of the analysis was that low solidity fine fiber beds -- ($\gamma = 0.02$), the ratio of filter volume occupied by fibers -- could be expected to provide high filtration efficiency for fine particles; that is, even when loosely packed, fine (3 μm) diameter ceramic fibers should provide high efficiency filtration performance. Results of this analysis showed that low solidity fine fiber ceramic filters with basis weight $\cong 500\ g/m^2$ theoretically capture 0.5 μm particles at 90 percent efficiency (Reference 5). The analysis also indicated that filters could perhaps be designed to operate at a filter face velocity of up to 15 cm/sec and still maintain high efficiency.

Room Ambient Filter Media Tests

A large number of ceramic fiber filter media candidates were subjected to a series of filtration tests at room ambient conditions. These tests also included some examples of conventional filter media for comparision purposes. These tests included:

- Dioctylphtalate (DOP) smoke penetration as a function of airflow velocity
- Determination of maximum pore size (in micrometers)
- Measurement of permeability
- Flat-sheet dust loading using AC fine test dust (a standard 0 to 80 μm classified Arizona road dust). Overall collection efficiency and dust loading required to develop 3.7 kPa (15 inches H_2O) pressure drop were determined from this test which was operated at 10 cm/sec (20 ft/min) air-to-cloth ratio.

These data revealed which of the available ceramic media candidates would most likely provide good filtration performance. The data is provided in detail in EPA-600/7-78-194 and has also been reported previously (Reference 6). A summary of findings from these tests is given below:

- Several of the ceramic paper and felt materials are capable of removing fine particles at high efficiency without excessive filter weights

- The ceramic paper and felt materials had filtration characteristics and performed similarly to paper and felt commercial filter media in a series of filter media tests

- The ceramic woven materials in general were characterized by large pores and poor collection efficiency in the dust loading tests, but the parameter range exhibited by the various materials indicates that an acceptable woven ceramic filter media could probably be fabricated. Such filter media would, however, have the same limitations as currently available woven filters -- that is, acceptable performance would only occur at low air-to-cloth ratios

- "Blanket" ceramic fiber materials (felts) consisting of small diameter fibers (3.0 μm) appear to be the most promising materials for high temperature and pressure tests because they combine good filtration performance and relatively high strength

<u>High Temperature/Pressure Mechanical Durability Tests</u>

Two major questions concerning the suitability of ceramic fibers for HTHP filtration needed to be answered:

1. How durable are ceramic fiber structures when subjected to environmental conditions associated with filtration applications?
2. How well do ceramic fibers perform as filters in HTHP environment?

Concerning the first of these questions, three ceramic filter media configurations survived a test during which the filter elements were subjected to 50,000 cleaning pulses. These tests were set up to simulate approximately a year's operation of mechanical cleaning loads on the media at high temperature and pressure, and showed that the low solidity fine fiber bed filters were undamaged by pulse cleaning loads. They also showed that the fly ash dust cake was deposited essentially on the surface of the low solidity fine fiber bed media. Details of these tests were also reported earlier and in EPA-600/7-78-194.

5.2 HIGH TEMPERATURE/PRESSURE FILTRATION TESTS

Filter performance tests were intended to simulate actual filter operation at high temperatures and pressure for a period of 200 hours.

The filter media configuration selected as being most promising consisted of an approximately 1-cm-thick layer of SAFFIL alumina mat insulation material. This ceramic material was contained between two layers of knit 304 stainless steel screen. The stainless steel screen was suitable for these relatively short tests, but would probably not survive long term exposure to the PFBC environment. However, we have fabricated similar filter elements, substituting the stainless steel screen with a ceramic screen made using a leno weave. The ceramic screen and media filter elements have not yet been tested, but we are confident they will be satisfactory.

Three 200-hour tests were attempted and completed. The tests were performed at a media face velocity of 2.5 cm/sec (5 ft/min), 9 cm/sec (18 ft/min) and 4.8 cm/sec (9.5 ft/min), and were performed in that order.

The first 200-hour test was performed at a nominal air-to-cloth ratio of 5 to 1 (2.54 cm/sec). Pulse duration was 150 msec. Pulse interval was one cleaning cycle every 10 minutes. Pulse pressure was 1100 kPa. Cleaning was performed "off-line" with a 4-second bleed down followed by reverse flow for 2 seconds; the pulse superimposed followed by a 2-second settling period prior to continuing the filtration cycle. We now feel that the reverse flow portion of the cleaning cycle is unnecessary and that off-line pulse cleaning will be sufficient.

Exxon Miniplant fly ash was used as the test dust. A fine dust, D_{50} = 4 μm, was used for the first 75 hours. When this dust was no longer available, a coarse sample, D_{50} = 19 μm, was used for the remainder of the test.

Cumulative dust fed, total dust collected downstream, and overall collection efficiency by mass are plotted as function of time on Figures 4, 5, and 6. The inlet concentration for this test was high, having an overall average of 14.4 g/Nm^3. Shortly after the fine dust was substituted with the coarse, overall efficiency was reduced and the rate of penetration in weight per unit time was increased. At about 120 hours and again at 150 hours into the test, the rate of dust feeding was reduced. The rate of penetration seemed to follow this. These occurrences were consistent with leakage through a defect mechanism in the media. Visual examination of the inside surface of media after the test revealed it to be basically clean with some localized staining. Overall collection efficiency remained high throughout the test, never falling below 99.964 percent.

Outlet concentration as a function of time is shown on Figure 7. These results are lower on a mass basis than turbine requirements as reported by Sverdrup in EPA 600/9-78-004. The outlet concentrations for this first test were based on a flow of 0.566 Nm^3 per minute during the 200 hours that dust was being fed. They do not include the additional flow occurring during warmup and cooldown when the dust feeder was off. Because of various test rig difficulties, this first run was interrupted many times. Pressure drop was maintained at $<$0.75 kPa (3 inches H_2O) throughout the test.

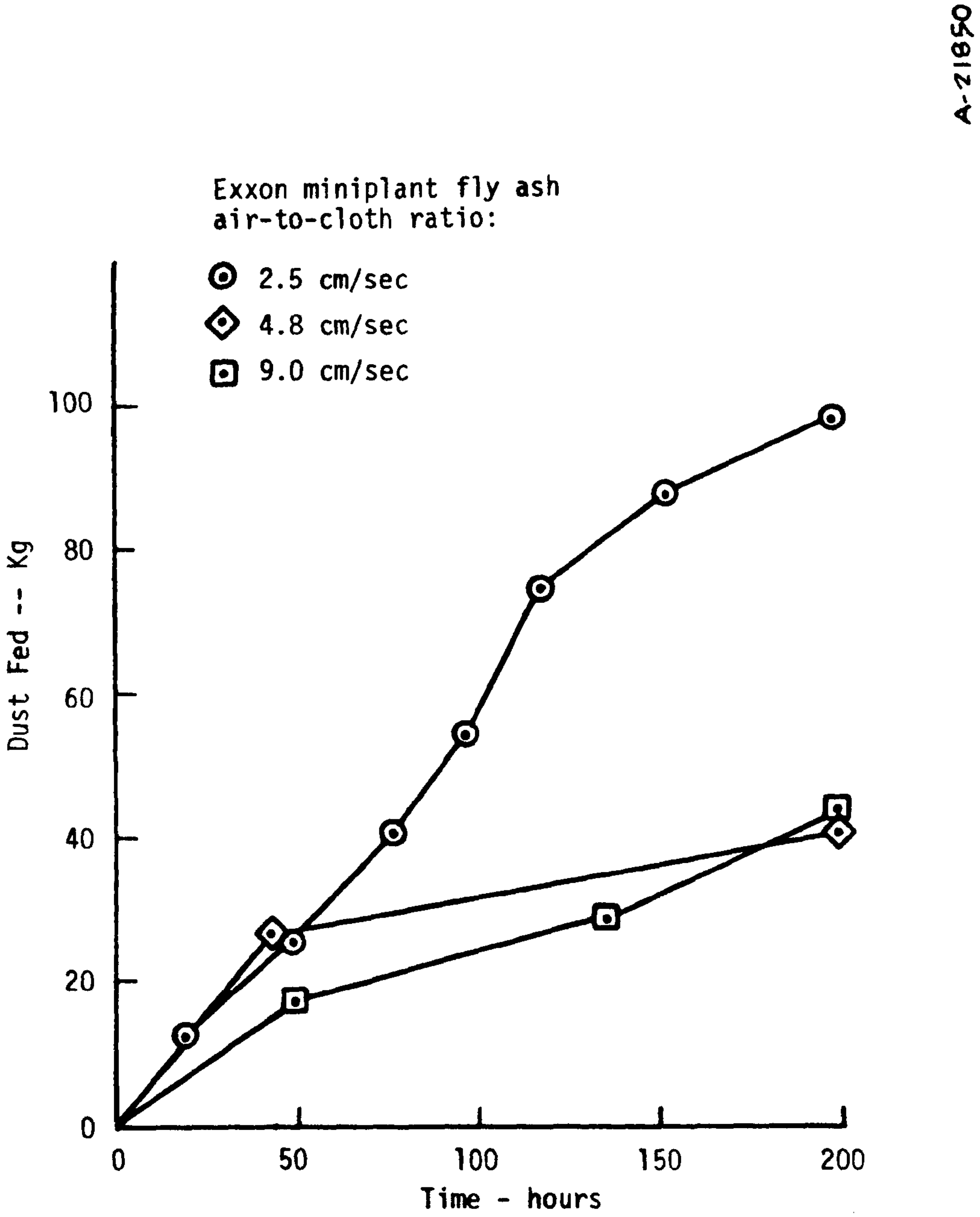

Figure 4. Cumulative dust fed.

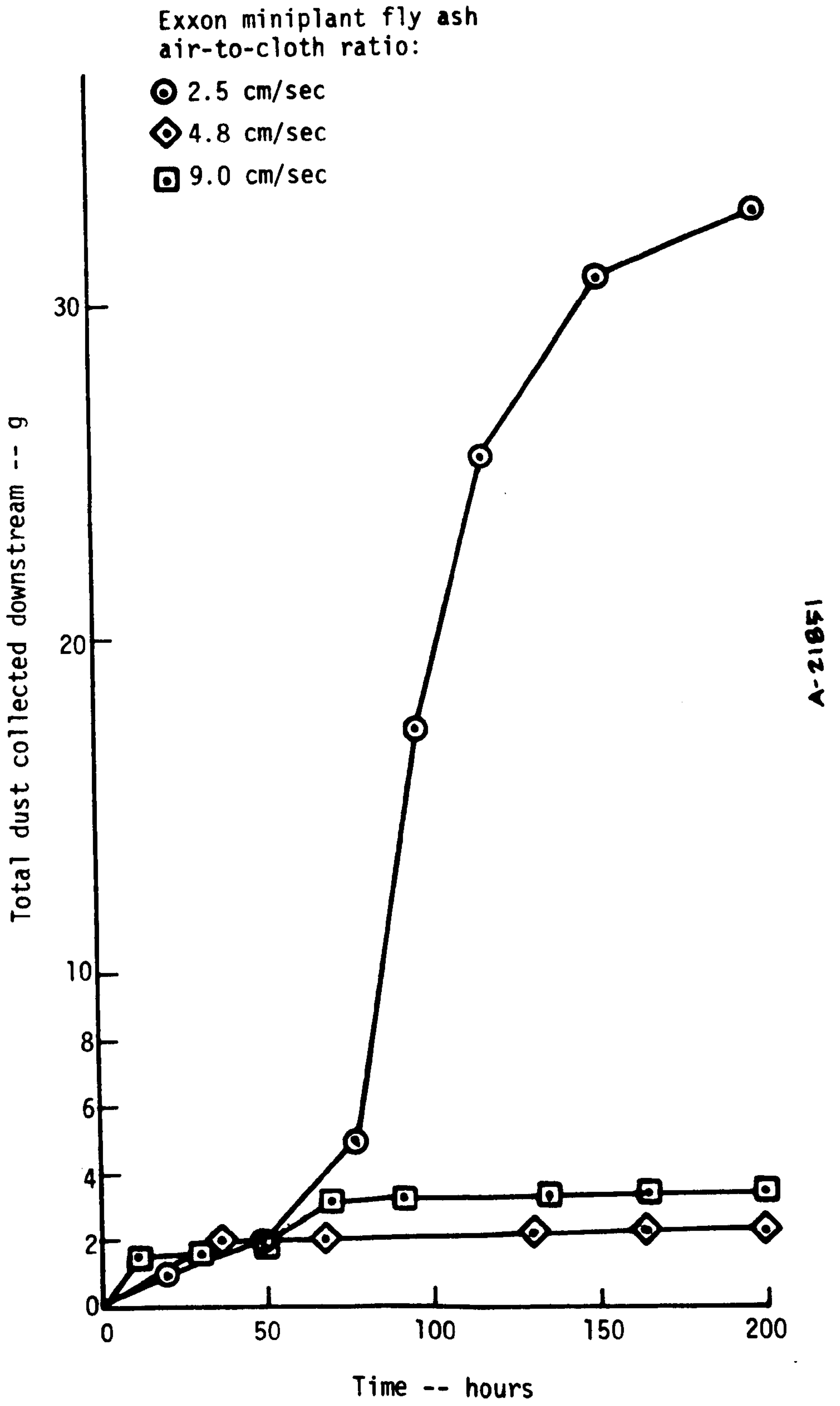

Figure 5. Total dust collected downstream.

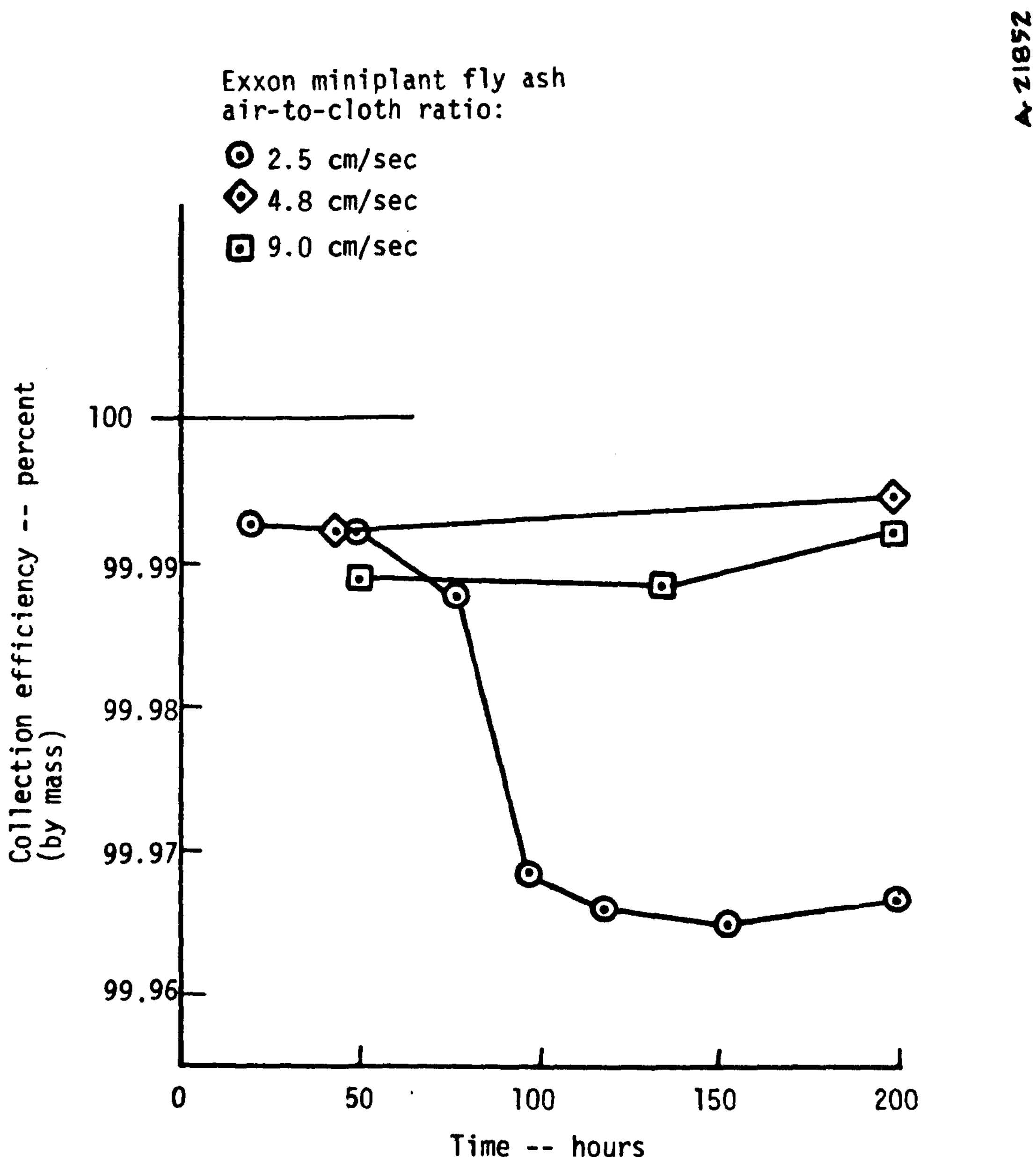

Figure 6. Overall collection efficiency.

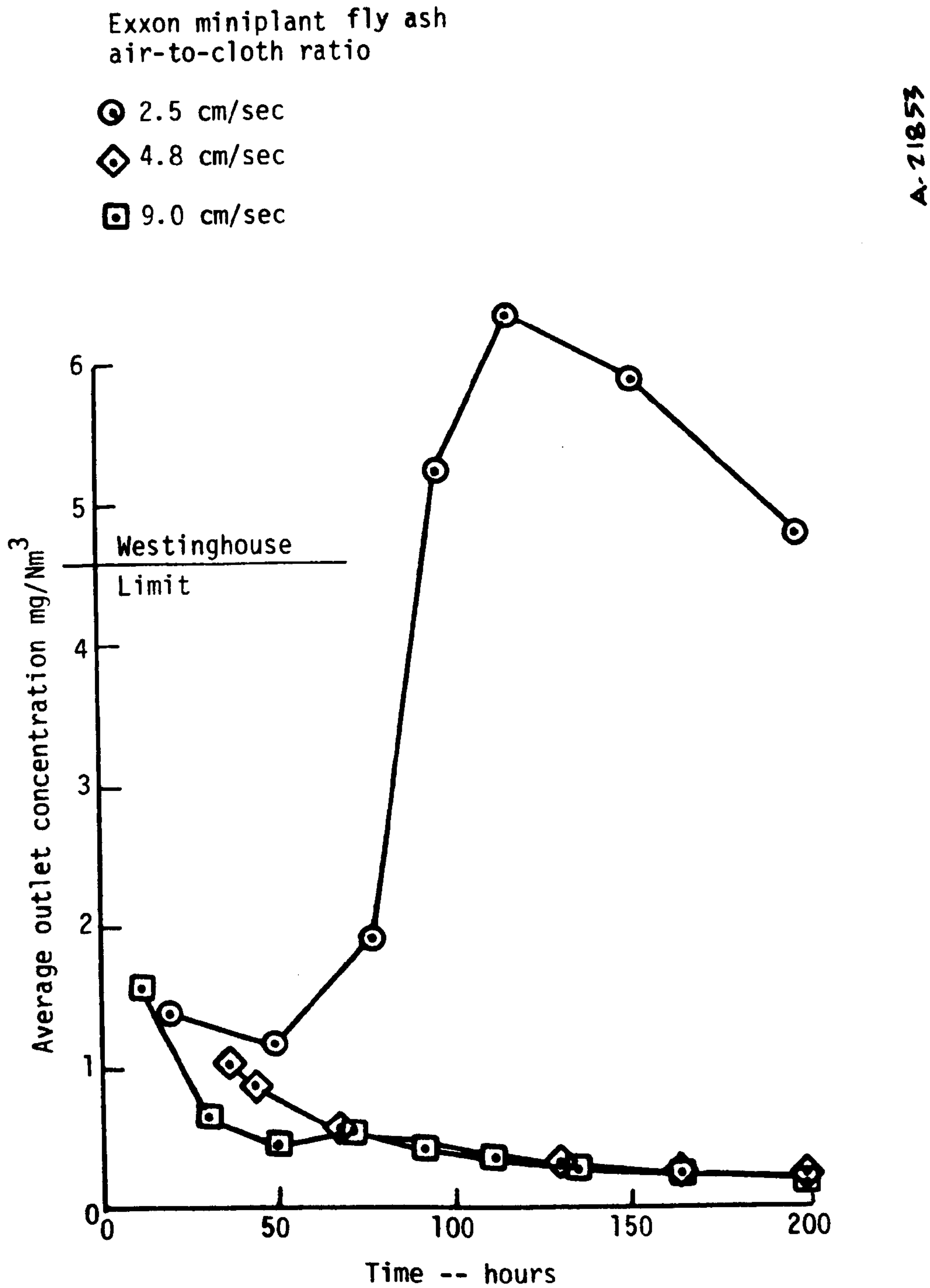

Figure 7. Average outlet concentration.

Subsequent test results showed lower outlet concentrations and led us to believe that the test filter used in the first test had a leak.

The second 200-hour test attempted to achieve the highest air-to-cloth ratio possible using the present test rig configuration. This test was performed at a filter media face velocity (air-to-cloth ratio) of 9 cm/sec (18 ft/min). Because of compressor limitations it was only possible to maintain a system pressure of 500 kPa. Earlier tests were performed at system pressures of 930 kPa. Cleaning pulse pressure was set at 860 kPa to compensate for the reduced system pressure. Cleaning cycle pulse duration and pulse interval were the same as in the previous test at 2.5 cm/sec with both tests using offline cleaning.

As before, fly ash from the Exxon Miniplant was used as the test dust. This dust had a D_{50} = 19 μm. Cumulative dust fed, total dust collected downstream and overall collection efficiency are plotted as a function of time on Figures 4, 5, and 6. Outlet concentration as a function of time is shown in Figure 7. Overall collection efficiency for 200 hours was 99.992 percent. The filter, which has only 0.146 m^2 (1.5 ft^2) of filter media area, removed 43,772 g (96.5 lb) of dust from 16,887 Nm^3 of air. Average inlet concentration was 2.59 g/Nm^3 and average outlet concentration for 200 hours was 0.2 mg/Nm^3. Thus, on a mass basis the outlet concentration is cleaner than projected turbine requirements. Pressure drop varied from about 0.5 kPa to 2.25 kPa (2 to 9 in H_2O) over the 10-minute cycle between cleaning events.

The third 200-hour test was performed at an intermediate air-to-cloth ratio of 4.8 cm/sec (9.5 ft/min). For this test, as for the higher velocity test, compressor limitations required that system pressure be set at 660 kPa. Cleaning pulse pressure was 1100 kPa. Other aspects of the cleaning cycle were the same as in the previous tests. The same dust was used (D_{50} = 19 μm). Cumulative dust fed, total dust collected downstream, and overall collection efficiency by mass are plotted as a function of time on Figures 4, 5, and 6. Outlet concentration as a function of time is plotted on Figure 7. Cleaned down pressure drop was maintained at less than 1.25 kPa (5 inches H_2O) throughout the test.

Outlet concentration as a function of face velocity (air-to-cloth ratio) is plotted on Figure 8 for three time periods of 50, 100 and 200 hours. If we assume the filter used in the first test at 2.5 cm/sec developed a leak and extrapolate expected performance (dotted lines), it is apparent that outlet concentration is reduced as a function of time at all velocities. This result is similar to what one would expect from a test using conventional filter media in a room ambient dust feeding test.

Overall particle collection efficiency is plotted as a function of face velocity (air-to-cloth ratio) on Figure 9 for three time periods of 50, 100 and 200 hours. Again, if the two discrepant data points are ignored, collection efficiency is substantially independent of face velocity in the range tested. This is consistent with a hypothesis which holds that filter penetration occurs primarily during cleaning. The filter was cleaned at zero forward flow in all three tests (off-line).

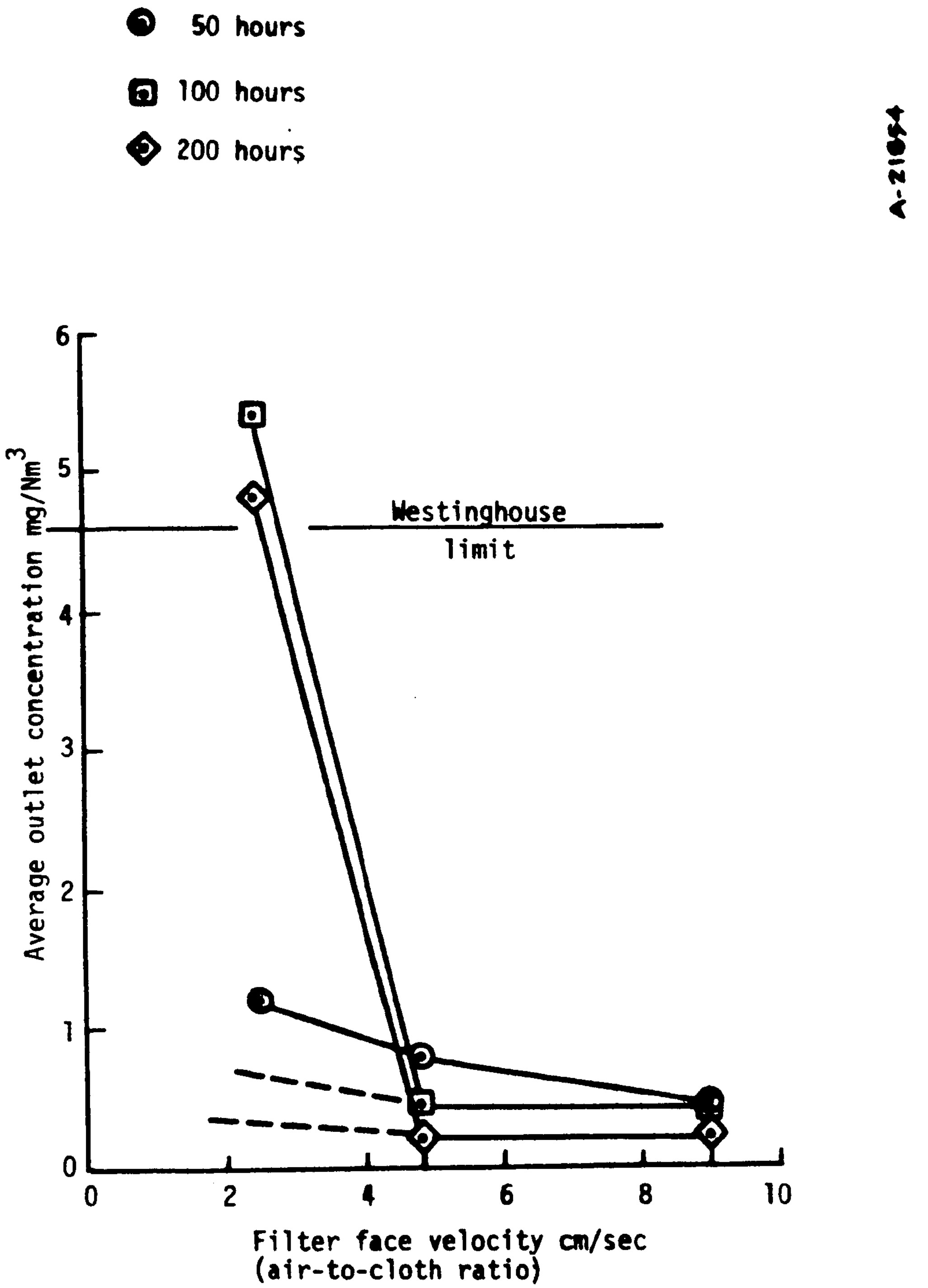

Figure 8. Outlet concentration as a function of face velocity.

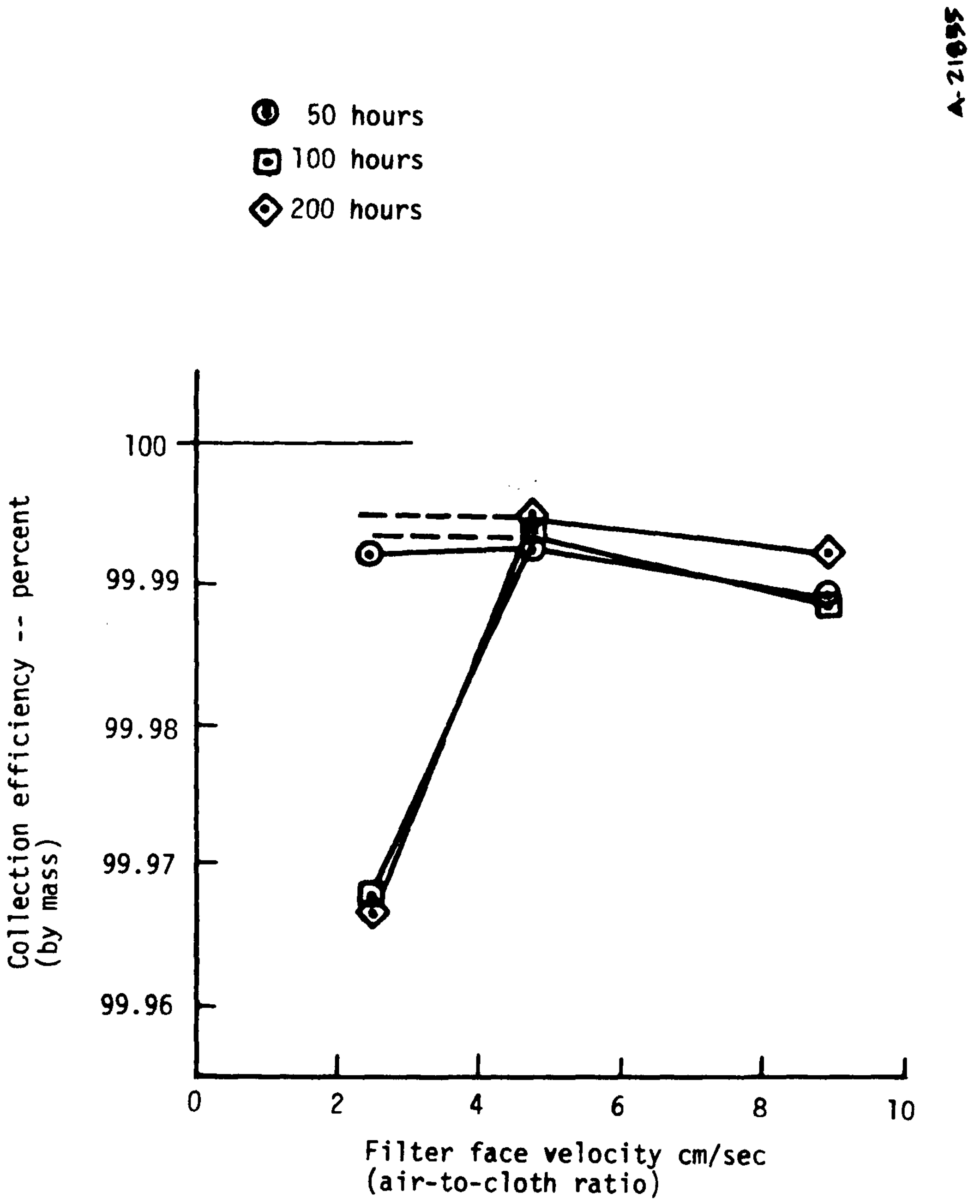

Figure 9. Collection efficiency as a function of face velocity.

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TECHNICAL REPORT DATA
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1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/7-79-112		

4. TITLE AND SUBTITLE	5. REPORT DATE
Extended Tests of Saffil Alumina Filter Media	May 1979
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
M.A. Shackleton	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Acurex Corporation 485 Clyde Avenue Mountain View, California 94042	EHE624A 11. CONTRACT/GRANT NO. 68-02-2611, Task 20
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	Task Final; 2/78 - 2/79 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Dennis C. Drehmel, Mail Drop 61, 919/541-2925.

16. ABSTRACT The report gives results of research aimed at developing filter media performance data under simulated pressurized fluidized-bed combustion conditions for one ceramic filter media candidate. A low-solidity fiber bed, using Saffil alumina ceramic filters was selected. Dust feeding was tested at a nominal 800 C and 10 atm pressure, using reentrained fly ash which had been collected at the EPA/Exxon Miniplant. Tests were performed at three filter media face velocities: 2.5, 4.8, and 9.0 cm/sec. Each test was 200 hours long. Pressure drop and collection efficiency were determined as functions of time and filter face velocity. Off-line cleaning by reverse pulse was effective in maintaining low pressure drop (<1.25 kPa) after a cleaning cycle. Collection efficiency was high (>99.9 percent) and was maintained over the 200 hour test. Collection efficiency was also substantially independent of face velocity over the range tested. Outlet concentration was less than the most stringent requirements proposed for turbine applications (generally <1 mg/cu Nm). Outlet concentration showed a trend toward lower values at higher filtration velocity. Mechanical durability was indicated in that none of the test filters appeared to have been damaged by the 200-hour tests with cleaning at 10-minute intervals.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Dust	Pollution Control	13B	11G
Filtration	Fly Ash	Stationary Sources	07D	
Combustion	Gas Turbines	Saffil Fibers	21B	13G
Fluidized Bed Processors		Particulate	07A	
Aluminum Oxide			07B	
Ceramic Fibers			11B,11E	

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