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HIGH-EFFICIENCY PARTICULATE REMOVAL WITH SINTERED METAL FILTERS*

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ABSTRACT

Because of their particle removal efficiencies and durability, sintered metal filters have been chosen for high efficiency particulate air (HEPA) filter protection in the off-gas treatment system for the proposed Idaho National Engineering Laboratory Transuranic Waste Treatment Facility. Process evaluation of sintered metal filters indicated a lack of sufficient process design data to ensure trouble-free operation. Subsequence pilot scale testing was performed with flyash as the test particulate. The test results showed that the sintered metal filters can have an efficiency greater than 0.9999999 for the specific test conditions used. Stable pressure drop characteristics were observed in pulsed and reversed flow blowback modes of operation. Over 4900 hours of operation were obtained with operating conditions ranging up to approximately 90°C and 24 vol% water vapor in the gas stream.

INTRODUCTION

Transuranic Waste Treatment Facility

During the past 26 years, thousands of tons of nuclear waste contaminated with transuranic (TRU) elements have been stored or buried at the Idaho National Engineering Laboratory (INEL). This waste, composed of both combustible and noncombustible materials, may be retrieved, processed, and shipped to a federal repository for permanent disposal. An attractive method for processing this waste is to convert it by means of a high temperature slagging pyrolysis incinerator (SPI) process into an inert, basalt-like solid that encapsulates the TRU elements. The SPI has been selected as a processing method to be incorporated into the INEL Transuranic Waste Treatment Facility (TWTF) (1).

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The major process operations in the TWTF will be waste receiving, waste preparation, incineration, slag handling, and off-gas treatment. The Waste Processing Building will incorporate the latest available technology in waste handling, fissile material assaying, criticality control, instrumentation, off-gas cleanup, remote operation/maintenance, and decontamination. Process equipment generally will be operated remotely using both local and central controls.

A key to ensuring safety and environmental acceptability for the TWTF is an efficient off-gas treatment system. The off-gas treatment system for the TWTF must establish effective control of radioactive and other potentially harmful airborne materials. Various off-gas treatment technologies were evaluated with respect to fine particle recovery for use in the TWTF. A detailed evaluation of the material balance of the incinerator off-gas stream indicated that high efficiency particulate air (HEPA) filters alone would become overloaded and plug after approximately 1/2 hour of operation. Therefore, some type of continuous particulate recovery equipment would be required in the off-gas treatment system.

The removal efficiencies of venturi scrubbers fall off rapidly for particles with aerodynamic diameters below about 1 μm, which makes their use impractical for this application. Electrostatic precipitators (ESP) also do not appear to have sufficient fine particulate removal efficiencies, and the design of an ESP requires far more information about the incinerator particulate than is available. Bag filters do not have a sufficiently fine particulate recovery efficiency for this application, and further, pose other safety problems for a secure radioactive materials off-gas treatment system. A dry off-gas treatment system using sintered metal filters (SMFs) was selected for development and design, based on SMFs high particulate removal efficiency, reduced maintenance (possibly in a remote environment), and absence of any secondary contaminated liquid waste. However, the lack of adequate design information for SMF's necessitated a pilot scale test program to verify the reported fine particulate recovery efficiencies and operating conditions. The description of this program is presented in the sections that follow.

Background of Sintered Metal Filters

The use of SMFs to remove particulate from a gas stream has been practiced for over 25 years (2). Yet, in this time, quantitative design equations have not been developed nor has a satisfactory explanation been given of how the filters operate without plugging over long operating times. These filters have been used in a variety of nuclear applications that are only partially documented with respect to operating conditions and particulate characterization. Industrial experience with SMFs is virtually nonexistent in the literature. While it is known that there are industrial users, limited contact with these users reveals their desire not to advertise certain aspects of their manufacturing processes. In the presentation that follows, experimental results are provided describing the operation of SMFs to remove flyash from a gas (air) stream where the primary objective was to obtain stable operation with respect to pressure drop and to obtain high particle removal efficiencies. These results were then used in the conceptual design of an off-gas treatment system for a radioactive processing facility that uses a SPI as described earlier.

EXPERIMENTAL PROGRAM TO TEST SINTERED METAL FILTERS

Purpose

The primary objective of the SMF test program was to verify the applicability of the filters in the INEL TWTF off-gas treatment system. Two criteria that were considered necessary for applying SMFs were particulate removal efficiency and stable pressure drop. The particulate size distribution used in the tests had to match or be finer than that expected from the SPI. The pressure drop requirements were stable operation at as low a pressure drop as practicable. A further objective was to test both blowback methods to determine any advantage of one over the other with respect to obtaining these primary objectives.

Basic System Description

The pilot plant apparatus used for evaluating the performance of the SMFs is shown in Figure 1. The major design considerations in the use of SMFs involve controlling the gas flow through the filter and providing blowback to clean the filter. A blower supplies air to the apparatus in which flyash is redispersed by an air ejector. The air/flyash mixture flowrate is measured and controlled prior to the filter vessel. Six cylindrical SMFs were installed in the vessel, with filter exhausts manifolded to provide a single off-gas stream for sampling. Total collection filters, or in-line filters, were used to quantitatively collect all entrained particles for SMF efficiency measurements.

An auger feeder gradually adds flyash to the ejector apparatus, which is supplied by an external pressurized 310 kPa air supply. The ejector consists of a stainless steel tube inserted in a tee to provide the aspirating action necessary to finely disperse the flyash into the gas stream. Gas flow measurements were accomplished using venturi and pitot tubes. The gas flow rate was maintained at an essentially constant value of 1.25 normal cubic metres per minute (Nm^3/min).

The main air supply is provided by a regenerative blower. The total flow from the blower is split into two streams: a main flow to the filters and a vent flow used to control the main flow rate. As filter pressure drop increases with time for a specified flowrate, the vent valve position provides the control variable necessary to maintain the desired flow.

The tested SMFs were cylinders 0.91 m long by 6.8 cm OD with a 0.15-cm wall thickness. The porosity of the filters was 0.5 absolute. One end of each filter element is capped, and the other end is connected to exit gas piping. Six filters were installed in a vessel 34.5 cm in diameter by 1.03 m long. A 60-degree cone was welded to the bottom for particulate collection following blowbacks.

The most important operating variable for an SMF appears to be the superficial velocity. The recommended superficial velocity determined by experience is usually 1.2 to 2.1 m/min, or sometimes even less, even though pressure drop versus superficial velocity for clean filters is advertised at considerably greater velocities (3,4).

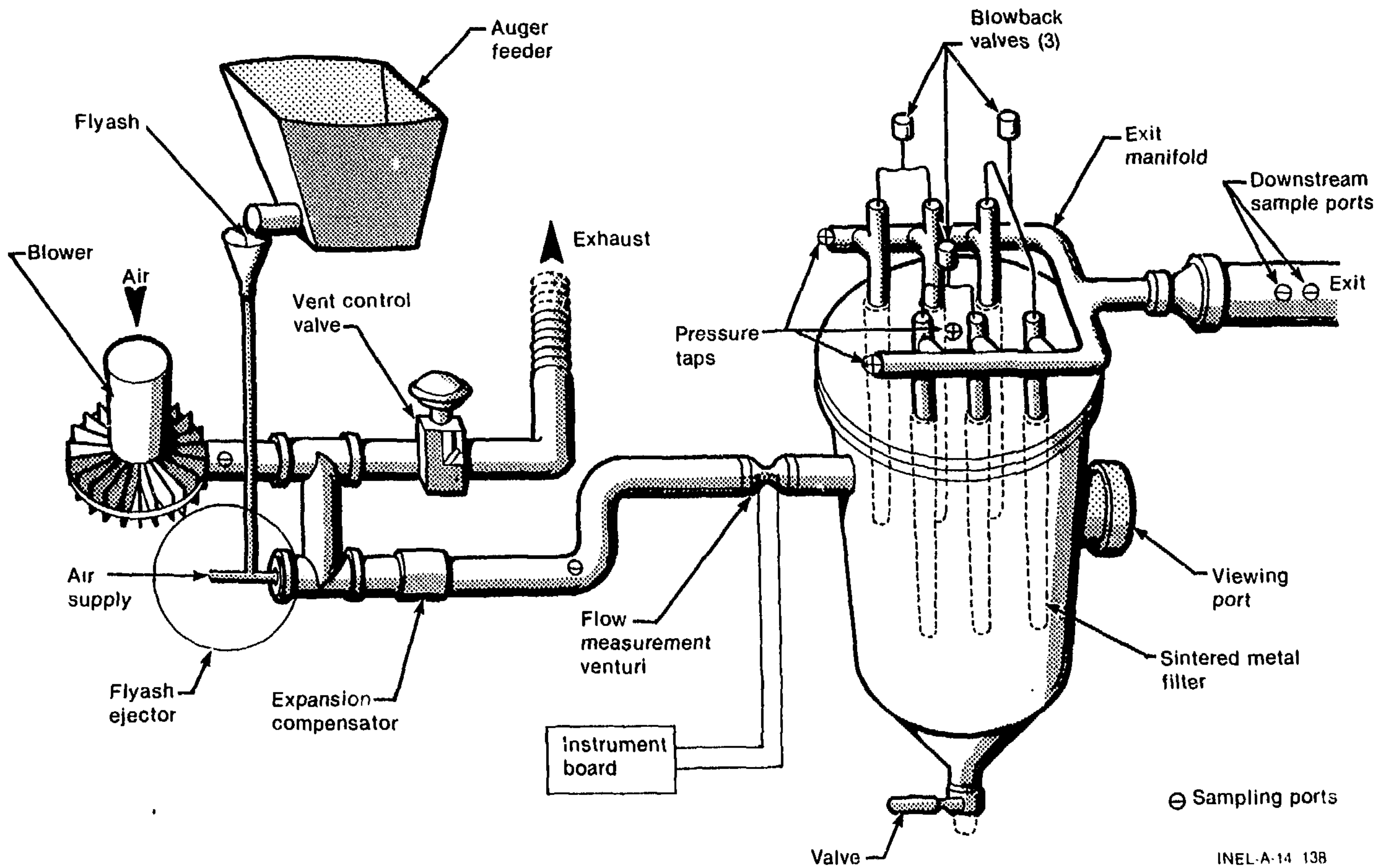

Figure 1. General Schematic of Pilot-plant apparatus for testing sintered metal filters.

During operation of the pilot plant system, the gas and particles enter the filter vessel such that the inlet stream does not impinge directly on a filter surface. A baffle was installed to distribute the gas and particles into the vessel. The gas and particles flow to the surface of the filter where the particles are collected, and the gas flows through the filter element. A pressure drop results due to the gas flow resistance of the porous metal and filter cake. The pressure drop increases with time due to the increasing cake thickness. When the pressure drop reaches a prescribed value (depending on the test), blowback is initiated.

Two blowback techniques were tested and evaluated based on literature (5,6) and vendor information: pulsed and reverse flow. In the pulsed blowback method, a tube or nozzle is directed to the filter exit. During blowback, a pulse of approximately 414 kPa air was delivered to a pair of filters for a fraction of a second through the blowback valves. Two filters were blown at a time with a 20-sec pauses between pulses until all filters were cleaned. During the series of SMF tests, the effect of blowback nozzle tube diameter was also investigated.

The reverse flow method uses a secondary air system (1.4 m^3/min regenerative blower) which operates continuously. During SMF loading, exhaust valves remain open and the reverse flow air is vented; the blowback air supply valves remain closed. When blowback is initiated (pressure drop controlled) the exhaust valves close and the blowback valves are opened, thus diverting the reverse flow blowback air through the filter set and into the vessel. This flow configuration is applied to two SMFs at a time for approximately 3 sec. The other pairs of filters are then sequentially blown back at 30-sec intervals.

<u>Test Program</u> (7,8)

Particulate Size Distribution and Loading

The particulate size distribution and loading of the redispersed flyash reaching the SMFs were measured by sampling after the filter vessel when no filters were installed. The reason for obtaining these measurements in this manner was that the filter vessel had an efficiency for particulate removal of about 60% for the flyash used. The filter efficiencies reported here are based on these downstream measurements to ensure that artificially high results are not reported.

The particulate size distribution expected from the SPI system is characterized by 100 wt% less than 32 μm in aerodynamic diameter, 50 wt% less than 10 μm, and 0.1 wt% less than 1 μm. The redispersed flyash that reached the SMFs in the laboratory system was finer than the incinerator par- ticles below 10 μm as measured by a cascade impactor. The particulate loadings to the filters were in the range of 3 g/Nm^3 with an initial flyash injection rate of 10 g/min into a gas flowrate of 1.25 Nm^3/min.

During the final stages of SMF testing, 5 wt% red iron oxide paint pigment in the flyash was used as the test particulate. The iron oxide was added to increase the percentage of fines, and cascade impactor measurements indicated that the iron oxide increased the submicron fraction by approximately 80%.

Sintered Metal Filter Efficiencies

The SMF filter efficiencies for both sets of filters were determined in a total of 15 tests. Two of these tests in the pulsed blowback mode lasted over 280 hours and yielded the highest estimates of particulate removal efficiency (greater than 99.99999% for flyash removal on a mass basis). In each long-term test, no mass change was observed on the filters. Since no mass change could be observed on these filters, a mass of 0.1 mg collected was assumed. The value of 0.1 mg was based on numerous experiments in the laboratory on filter handling procedures and repeated mass determinations. In other tests with reverse flow blowback, some discoloration of the filter was observed, but the mass gain was not measurable. This discoloration was determined to be due to the unfiltered blowback air. In the tests with iron oxide plus flyash, no red discoloration of the sampling filters was observed.

The conditions of the two tests conducted for over 200 hours were a superficial velocity of 1.16 m/min with a pulsed blowback initiation pressure drop of 6.25 kPa. The gas was air at ambient temperature and humidity and the temperature in the filter vessel was approximately $40^{o}C$. These conditions are referred to as the base condition.

Thirteen additional SMF tests at other conditions were made with gas particulate sampling times less than 200 hours. Since no mass gain on the sampling filters was observed, with one exception, the 0.1 mg gain was assumed. These tests yield efficiencies on the order of 99.999%. The one exception, where a mass change was observed on the filter, was attributed to the downstream piping being contaminated with flyash due to previous cascade impactor measurements. Subsequent recleaning of the piping resulted in no mass increase of the sampling filters. Pressure indications also showed that no gross loading of particulate was occurring on the in-line filters.

It must be noted that a determination of the absolute particulate removal efficiency of the SMFs was not possible with the hardware and techniques used. Only bounded estimates could be obtained for the particulate source used.

Pressure Drop Characteristics

The porous SMF pressure drop immediately after blowback is called the recovery pressure drop. For stable operation, this pressure drop must remain well below the blowback initiation pressure drop. The recovery pressure drop after every blowback in the tests described here was recorded. In the pulsed blowback mode, the initiation pressure drop was 6.25 kPa. The recovery pressure drop appears to stabilize at 3.75 to 4.25 kPa.

Over 100 blowback cycles were required to attain apparently stable operation. These test results do not indicate infinitely stable pressure drop characteristics; however, the data for over 400 cycles on two different sets of SMFs did not indicate an increasing trend in the recovery pressure drop.

Reverse flow blowback tests were conducted at the base condition. Initially, the reverse flow superficial velocity was one-half the forward velocity and resulted in a recovery pressure drop only slightly below the initiation pressure drop. Increasing the reverse flow superficial velocity to 1.2 m/min resulted in a recovery pressure drop of 4.5 kPa for over 250 cycles.

Other tests conducted on pressure drop characterizations include variation of the blowback initiation pressure drop, increased superficial velocity, particulate size distribution change, and temperature and humidity changes of the process air stream. Changing the pulse blowback initiation pressure drop had no observable effect on the recovery pressure drop at the base condition. However, increasing the superficial velocity did result in an increase in the recovery pressure drop. Returning to the base condition after increasing the superficial velocity did not result in the prior recovery pressure drop. It appears that the porosity and/or thickness of the permanent cake on the filter are determined by the highest superficial velocity. Changing the particulate size distribution with iron oxide, as previously noted, had no effect on the recovery pressure drop compared to the base condition.

Probably the most significant tests with respect to pressure drop characteristics were performed with conditions of high humidity and temperature. By injecting steam into the air process stream, a gas composition containing approximately 24 vol% water vapor was obtained. The process stream was heated to approximately 90°C to maintain a dry system. These conditions resulted in a rapid increase in the recovery pressure drop from 4.5 kPa at the base condition to greater than 5.2 kPa. Temperature alone was the variable that affected the recovery pressure drop. This was determined by allowing the system to stabilize with steam injection, then stopping the steam injection, and finally shutting down the process heater. There was no change in the recovery pressure drop when the steam was stopped, but the recovery pressure drop decreased to 3.9 kPa as the air stream cooled down after the process heater was shut down. Repeated applications and removal of heat appeared to indicate that the change in pressure drop is reversible. This pressure drop change with respect to temperature appears to be due to a change in porosity and viscosity, and has been quantified for a clean SMF.

CONCLUSIONS

Particulate Removal Efficiencies

The SMF particulate removal efficiencies reported here were obtained from a specific experiment. The efficiency of the SMFs are absolute in the sense that no measurable particulates were ever collected downstream from the filter vessel. The estimated efficiencies are on the order of 99.99999%, based on the minimum assumed mass gain of downstream collection filters. This estimate is limited by the efficiency of the collection filters themselves, which were HEPA filters. Other detection methods for particulate passing through the SMFs could very well yield a different result, but the detection method used in these experiments is similar to the intended application of HEPA filter protection. The efficiencies reported here are only for the particulate size distribution used and should not be interpreted or applied in any other sense.

Pressure Drop Characteristics

The pressure drop across the SMFs appeared to stabilize after an initial startup period. The pressure drop of interest is the recovery pressure drop that occurs immediately after blowback. It is not possible to demonstrate a nonplugging operation in an absolute sense, but only over the time frame of an actual test. The pressure drop characteristics reported here are only for the specific conditions and flyash tested. Over 4900 hours of operation with over 5100 blowbacks were conducted on SMFs with no apparent plugging observed.

Other Applications of SMFs

A process design engineer is reluctant to use a unit operation that is not well understood. In the case of SMFs, there are very few large applications of thousands of square feet of SMFs not only because of the cost, but also because of the lack of design equations. On the other hand, there are numerous applications involving hundreds of square feet of SMFs, where the relative size involved presents a smaller risk to the user. At the present, it appears that data and design information are emerging that will make rigid barrier filters usable in such systems as incinerator flue gas filtration, extreme temperature environments, and where extremely high particulate removal efficiencies are required on a continuous use basis.

ENDNOTES

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