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Experimental Investigation of In Situ Cleanable HEPA Filter

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Abstract

The Westinghouse Savannah River Company located at the Savannah River Site (SRS) in Aiken, South Carolina is currently testing the feasibility of developing an in situ cleanable high efficiency particulate air (HEPA) filter system. Sintered metal filters are being tested for regenerability or cleanablity in simulated conditions found in a high level waste (HLW) tank ventilation system. The filters are being challenged using materials found in HLW tanks. HLW simulated salt, HLW simulated sludge and South Carolina road dust. Various cleaning solutions have been used to clean the filters in situ.

Figure 1 is a sketch of a typical SRS HLW tank. The tanks are equipped with a ventilation system to maintain the tank contents at negative pressure (-1.0" water column) to prevent the release of radioactive material to the environment. This system is equipped with conventional disposable glass-fiber HEPA filter cartridges. Removal and disposal of these filters is not only costly, but subjects site personnel to radiation exposure and possible contamination.

A test apparatus was designed to simulate the ventilation system of a HLW tank with an in situ cleaning system as depicted in Figure 2. Test results indicate that the Mott sintered metal HEPA filter is suitable as an in situ cleanable or regenerable HEPA filter. Data indicates that high humidity or water did not effect the filter performance and the sintered metal HEPA filter was easily cleaned numerous times back to new filter performance by an in situ spray system as shown in Figure 3, 4 and 5. The test apparatus allows the cleaning of the soiled HEPA filters to be accomplished without removing the filters from process. This innovative system would eliminate personnel radiation exposure associated with removal of contaminated filters and the high costs of filter replacement and disposal. The results of these investigations indicate that an in situ cleanable HEPA filter system for radioactive and commercial use could be developed and manufactured.

Introduction

For the past several years, personnel from SRS, Lawrence Livermore National Laboratory, and Oak Ridge National Laboratory have been investigating the use of cleanable or regenerable HEPA filters to replace conventional disposable HEPA filters. The results of these investigations indicate that commercially available technologies could be applied to develop and manufacture a filtering system that would meet the performance criteria of a conventional HEPA filter and is cleanable or regenerable in situ. In other words, when the performance of the filter drops below specified minimums, the air flow and the differential pressure across the filter could be restored to a clean filter status without being removed from the filter housing (in situ restoration) and with minimal labor. Studies and testing have been conducted to determine the feasibility of washing HEPA filters in situ after becoming plugged with the simulated solutions found in the high level waste (HLW) tanks at SRS.

The HLW tanks hold approximately 1.3 million gallons of high level radioactive waste. The tanks are located outdoors and equipped with a ventilation system to maintain the tank contents at negative pressure (-1.0" water column). The negative pressure prevents the release of radioactive material to the environment, yet also allows for atmospheric dust to be pulled into the tank. Figure 1 depicts the general layout of the ventilation system found on a typical HLW tank. The ventilation system of these tanks are equipped with conventional disposable glass-fiber HEPA filters which requires routine removal, replacement, and disposal of these filters. During the filter change out, site personnel are subjected to radiation exposure and the used filters contribute to an ever-growing waste disposal problem.

The glass fiber HEPA filters must exhibit a particle removal efficiency of 99.97% when challenged by thermally generated monodispersal dioctylphthalate (DOP) smoke particles with a diameter of 0.3 microns. Process HEPA filters at SRS are required to pass an in-place leak test per site requirements before being placed into service. DOP tested connectors were designed into the test apparatus to complete an in-place leak test per National and Site Standards on the test filters.

The Savannah River Technology Center (SRTC) located at SRS designed and constructed a test apparatus as shown in Figure 2, to closely simulate the conditions found on a HLW tank and allow for testing to be conducted on two filters at once. The test apparatus was designed such that one filter could be cleaned while the other remain in testing. The apparatus operated continuously (24 hours a day, 7 days a week) with the test filters filtering the entrained particles from the air stream until the filter plugged. These particles are believed to be responsible for plugging the existing HEPA filters in the HLW tanks. The apparatus was designed for approximately 20 scfm of filtered air to flow into a waste tank filled with approximately 30 gallons of heated (60°C) simulated HLW solution. The waste tank heaters were tied to high temperature interlocks that would shut down the heaters if the tank temperature exceeded 75°C. The simulated solution was agitated while the filtered air traveled through the headspace of the tank, simulating the flow path of the HLW tank ventilation system. From the tank the airflow split, with approximately 9 scfm of air passing through each test filter. A separate vacuum pump was used to pull the air across each filter as shown in Figure 2. The primary components of the test apparatus includes the simulated waste tank, two filter housings, two vacuum pumps, data acquisition system and an in situ filter cleaning system. The filter housings contain four evenly spaced spray nozzles that distribute the cleaning solution through a positive displacement pump over the entire filter surface.

Testing was initially conducted on two filters but one filter failed very early in the test program after wetting and is not discussed in the contents of this report. The successful in situ cleanable filter was a sintered metal Mott filter, which was provided by Mott Corporation, located in Farmington, Connecticut. The filter medium was constructed using 1-micron 316L stainless steel particles, sintered into a 2" diameter by 4" long with a filter medium thickness of 0.020". The filtration area of the Mott Filter was 25 in^2. The filter has a pressure drop of approximately 160" w.c. with 9 scfm of airflow.

The following three materials were used to challenge the filters. The materials simulate the waste found in the HLW tanks and atmospheric dust:

- Simulated HLW Salt
- Simulated HLW Sludge
- South Carolina Road Dust

The simulated solutions did not contain radioactive materials and only one solution was in the waste tank at a time. However, the tank was empty while testing with the SC road dust. The dust was used to simulate atmospheric dust found around SRS. The SC dust consisted of topsoil taken from a garden in Aiken County. The soil was dried in an oven to remove the moisture and particles larger than 75 microns were sifted out, giving a large distribution of particle sizes to challenge the filter. Testing was conducted first with simulated HLW salt. Further testing was done with a concentrated salt solution, which was created by evaporating off water to create dry salt in the tank. At the end of the salt test, the solution was removed from the tank and the simulated HLW sludge was then added to the tank. The water was also evaporated from the sludge to create a dry sludge tank.

The waste tank was operated with approximately 28" (30 gallons) of simulated HLW salt or sludge in the tank. During the dry salt and dry sludge test, the tank level was maintained at approximately 18". Simulants were vigorously agitated in the waste tank while a temperature of approximately 60°C was maintained. When required, water was added to the waste tank to account for evaporation. The simulated waste tank operated under a small vacuum, (approximately 1" w.c.) which is normal operating pressure in the HLW tanks.

At the end of the sludge test, the tank was emptied and cleaned out. The SC road dust was added to the dust reservoir, which was connected to the DOP test connector port as shown in Figure 2. The dust was slowly injected into the 9 scfm air stream using a small purge of house air.

Vacuum pumps pulled approximately 9 scfm of air through the clean test filters. Variable speed controllers and pressure control valves were used to obtain 9 scfm of airflow with a clean filter. Once the variable speed and pressure control valves were set for a given filter, the settings were not changed for the duration of the test.

After a filter became soiled or plugged, it was cleaned using the in situ cleaning system shown in Figure 2. The sintered metal filter was cleaned via spraying the inlet side of the filter with nitric acid and/or sodium hydroxide and/or water. The filter was also completely plugged or dead headed (i.e., no flow across the filter) during the test program to determine the cleanability from a worst case scenario. A dual diaphragm pump was used to spray cleaning solutions on the air inlet side of the filter. The filter was not back flushed but is an option for future testing. After cleaning, the filter was allowed to drip-dry for approximately one hour before returning to operation for further testing.

The data from the experiment was recorded by the data acquisition system (DAS) using calibrated instrumentation. Data that were recorded by the DAS includes differential pressure (dP) and flow across the filters, humidity and temperature in the filter housings, and the temperature of the simulated waste tank.

Results

The first filter performance test on the sintered metal filter was a standard in-place leak test of HEPA filters per national standards. The filter passed the test with 99.99% removal efficiency. However, the DOP material partially plugged the sintered metal filter. Soaking the filter in methanol followed by air-drying, cleaned the filter. The test engineer indicated that the quantity of DOP material used to challenge the small filter far exceeded the amount needed for a 9-scfm filter.

The sintered metal filter was then tested with water in the waste tank (see Figure 2) to determine if the filter could operate in a high humidity environment without plugging due to high moisture in the air stream. The water was agitated and heated to approximately 60°C with the humidity in the filter housings at approximately 100% and water standing in the bottom of the filter housings. The high moisture content of the air had little or no effect on the operation of the filter.

The performance of the sintered metal filter was then tested with a simulated salt solution in the test apparatus waste tank. The dry salt simulated conditions found in the HLW dry tanks such as HLW Tank 9. During this time the waste tank agitator speed was increased to accelerate filter plugging by increasing the generation of droplets and particulates carried-over to the filter. With dry salt in the simulated waste tank, a hostile environment was created and the filter plugged (20% or more decrease in flow) in approximately 24 hours. The short plugging time is believed to be due to dusting from the salt cake, however no buildup of salt particles could be seen on the surface of the filter by visual inspection. The sintered metal filter was cleaned in situ using nano pure water five times during the 160-hour dry salt run. Each time the airflow and dP across the filter recovered as shown in Figure 3. After the second cleaning cycle, the filter was plugged completely and the vacuum pump continued to operate deadheaded for 50 hours with vacuum as high as 29.5" Hg on the suction side of the filter. This allowed for the small salt particles to be pulled into the filter's 1µm nominal flow channels, potentially making it more difficult to clean the filter. After cleaning the filter in situ, the airflow and filter dP recovered immediately.

The sintered metal filter was then tested using only simulated HLW sludge in the waste tank. The sludge simulates conditions found in HLW sludge tanks such as Tank 12. After approximately 600 hours of operation, the filter had not plugged. The filter was not impacted by the simulated HLW sludge until the water was allowed to evaporate off the sludge in the waste tank, creating a dry sludge. The dry sludge allowed particulate matter to be entrained easily in the air stream, creating a environment where the filter would plugged rapidly. Unlike the simulated salt, the sludge was quite visible on the surface of the filter. During initial in situ cleaning of the sludge; water, hot water and hot detergent water failed to clean the simulated HLW sludge off the filter. 10% nitric acid was found to do a good job of cleaning the sludge off the filter. The airflow and dP across the filter was restored to normal as shown in Figure 4. Approximately 3 gallons of 10% nitric acid and 3 gallons of rinse water were used to clean the filter in situ.

To determine if a cleaning solution could be used for more than one cleaning cycle, used nitric acid was used to clean the sintered metal filter between 500 to 600 hours of operation time. Figures 4 shows that the airflow across the filter continued to degrade while using this recycled dirty cleaning solution for the in situ cleaning. Therefore, using a cleaning solution for more than one cleaning cycle is not recommended.

The final test was conducted using South Carolina road dust to challenge the sintered metal filter. The SC road dust simulates the atmospheric dust in-leakage that may occur on the HLW tanks. The dust was placed into a dust reservoir and slowly injected into the air stream using a small purge of house air. The filter was plugged three times using SC road dust. Each time the airflow and dP across the filter recovered as shown in Figure 5. The filter was cleaned in situ with 10% nitric acid and rinsed with water. The last in situ cleaning was conducted using 10% nitric acid, rinsed with water, 10% NaOH and rinsed with water. Unlike the simulated salt, the SC road dust was quite visible on the surface of the filter. Even with all visible dust in the filter housing and on the surface of the filter, the filter did not deadhead during a heavy loading of the filter from 275 hours to 600 hours of operation as depicted in Figure 5.

The sintered metal Mott filter has operated in a controlled but very hostile environment using simulated HLW salt and sludge and SC road dust. The filter had been plugged and cleaned in situ many times with the airflow and dP across the filter recovering after each cleaning.

An emerging issue for HLW Tank Farm operations is the unknown quantity of radionuclide that may be accumulated on the HEPA filter. Since there exists no practical way of determining buildup of alpha and beta emitters, release of these radionuclide to the environment from a catastrophic HEPA filter failure has become a concern. The application of the in situ cleanable filter could potentially prevent buildup of alpha and beta emitters. The filter could be washed in situ to remove particulate matter build up and analyze the wash water to measure buildup verses operating time, and predict the result of a catastrophic failure. Once the accumulation rate is confirmed the filter could be procedurally washed to prevent excessive build-up. The in situ cleanable filter could potentially be used in other related applications such as recovering valuable material such as precious metals that may collect on a glove box HEPA filter.

Conclusions

Test results indicated that an in situ cleanable or regenerable HEPA filter system is feasible using sintered metal as the filter media. The sintered metal Mott filter was tested in a simulated but hostile environment where the filters would plug rapidly with HLW simulated salts, simulated HLW sludge or South Carolina road dust. After plugging in the simulated conditions, the filter was easily cleaned and recovered to approximately the original dP and airflow even after numerous in situ cleaning cycles. The sintered metal filter passed the standard In-place leak test of HEPA filters and high humidity and water had little or no effect on its performance. Test data indicates promising results and shows that the sintered metal filter is suitable as an in situ cleanable HEPA filter for ventilation systems and could potentially be used to recover precious metals from filtration processes.

Figure 1

Typical HLW Tank Ventilation System Flow Diagram

Figure 2

Test Apparatus

Figure 3

Figure 4

Figure 5