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GRANULAR FILTRATION IN FLUIDIZED-BED

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ABSTRACT

Successful development of advanced coal-fired power conversion systems often require reliable and efficient cleanup devices which can remove particulate and gaseous pollutants from high-temperature high-pressure gas streams. A novel filtration concept for particulate cleanup has been developed at the Morgantown Energy Technology Center (METC) of the U.S. Department of Energy. The filtration system consists of a fine metal screen filter immersed in a fluidized bed of granular material. As the gas stream passes through the fluidized bed, a layer of the bed granular material is entrained and deposited at the screen surface. This material provides a natural granular filter to separate fine particles from the gas stream passing through the bed. Since the filtering media is the granular material supplied by the fluidized bed, the filter is not subjected to blinding like candle filters. Because only the in-flowing gas, not fine particle cohesive forces, maintains the granular layer at the screen surface, once the thickness and permeability of the granular layer is stabilized, it remains unchangeD as long as the in-flowing gas flow rate remains constant. The weight of the particles and the turbulent nature of the fluidized bed limits the thickness of the granular layer on the filter leading to a self-cleaning attribute of the filter. Filtration performance of the filter was first reported at the 12th International Conference on Fluidized-Bed Combustion, which the filtration system was operating only at a batch mode. This paper presents work since then on a continuous filtration system.

The continuous filtration testing system consisted of a filter, a two-dimensional fluidized-bed, a continuous powder feeder, a laser-based in-line particle counting, sizing, and velocimeter (PCSV), and a continuous solids feeding/bed material withdrawal system. The two-dimensional, transparent fluidized-bed allowed clear observation of the general fluidized state of the granular material and the conditions under which fines are captured by the granular layer. A series of experiments were conducted at various ranges of operating conditions with two different bed materials: a 30 x 270-mesh acrylic powder with particle density of 1.1 gm/cc and a 40 x 270-mesh Millwood sand, which has particle density of 2.5 gm/cc. During the experiments, fine sand (less than 100 microns) was fed continuously to the bed through the powder feeder at a constant rate of 3.8 gm/min (0.5 lb/hr). Bed material and captured fine particles were withdrawn continuously through an overflow tube. In order to maintain a constant bed level, makeup bed material was also fed continuously through a non-mechanical valve to the bottom of the fluidized bed. Performance of this granular filtration system was measured by the PCSV at downstream of the filter.

High filtration performance was measured when lower density powder was used as bed material. Collection efficiencies over 99 percent were obtained with this bed material in a continuous flow mode. Low filtration performance was experienced with heavier bed material. The low filtration performance with this material may be attributed to the failure of maintaining a sufficiently thick granular layer at the screen filter surface. Filtration performance as a function of particle size distribution and the pressure drop across the granular filter are also discussed in this paper.

INTRODUCTION

Successful development of advanced coal-fired power conversion systems often requires reliable and efficient gas-stream-cleanup devices that can remove particulate and gaseous pollutants from high temperature and high pressure gas streams. A novel filtration concept, fluidized-bed granular filtration, for particulate cleanup has been developed at the Morgantown Energy Technology Center (METC). The fluidized-bed granular filter consists of a fine screened surface immersed in a fluidized bed of granular material. As the gas stream passes through the fluidized bed, a layer of fine granular material is deposited and packed at the screen surface, which provides a natural filter to separate the fine particles from the gas stream. Since the filtering media is the granular material supplied by the fluidized bed, the filter is not subjected to blinding. Cleaning the filter (if necessary) is much easier than with a ceramic filter because only the inflowing gas maintains the filter media at the screen surface. Therefore, the screen surface can be readily cleaned by momentarily interrupting the gas flow. The primary objective of this project is to demonstrate the technical feasibility of the fluidized-bed granular filtration concept. The specific goals of this project include the following objectives:

- Design, construct, and operate a cold flow model to obtain engineering data which include filtration performance and system operability for the future design of hot model.
- Design and demonstrate the technical feasibility of the fluidized-bed granular filtration concept in a hot model.

PROJECT DESCRIPTION

Concept Description

A fluidized-bed granular filtration system, shown in Figure 1, generally consists of a metal screen filter supported by a perforated tube immersed in a fluidized bed. The bed material is entrained by a gas to form a granular layer of bed particles at the surface of the filters. The formation and maintenance of this layer of bed particles is the essential feature of the fluidized-bed granular filter concept. This deposited layer of particles creates a filtration medium (much like a granular-bed filter) that is capable of removing fine particles from the gas stream. This method of filtration combines the advantages of both granular-bed filters and porous, ceramic filters. Because the actual filtration media is bed particles, the fluidized-bed granular filter is not subject to blinding like ceramic filters. Cleaning is also easier. In the fluidized-bed granular filter, only in-flowing gas maintains the filter media. Thus, the filter can be readily cleaned by momentarily interrupting the gas flow. The filter may in fact be self cleaning since the buildup of fine material reduces the gas flow. This eliminates the force holding the particles to the screen and causes the excess of bed particles and collected fines to fall from the granular layer into the bed. Furthermore, the fluidized bed also provides turbulent motion for scouring and cleaning of the filter surface.

Experimental Test Facility and Operation

The cold model of a fluidized-bed granular filtration system is shown schematically in Figure 2. The model is a two-dimensional fluidized bed with a vertical, metal-screen filter arrangement. The fluidized bed is 12 inches wide, 1.5 inches thick, and 36 inches high.

The two-dimensional fluidized-bed consists of a freeboard section, a fluidized bed section, and an air plenum chamber. Both the freeboard and fluidized bed section are made of four 14-inch by 18 3/4-inch aluminum section. Each section has a 12 1/2-inch by 18-inch clear Lexan window so the behavior of the bed can be observed through the transparent front and back walls. This allowed observation of the general fluidized state of the bed and the conditions under which a particle layer is formed. In tests where a fine dust was added to the bed, the collection of fine dust by this particle layer can also be observed. The fluidized bed is separated from the plenum chamber by an air distributor, which consists of a 200-mesh metal screen sandwiched between two 1/8-inch thick rectangular stainless-steel plates that are drilled with 1/8-inch nozzles. The 12-inch by 1 1/2-inch by 12-inch plenum is made of 1/8-inch thick stainless steel and serves as the fluidizing air header and also circumvent any preferential air flow to the air distributor.

A single, vertical, screen filter element is inserted into the bed. The filter element, shown in Figure 3, consists of a 1-inch by 1-inch square tube perforated on two opposite sides of the square tube. The filter is entirely enclosed with a 100-mesh (149 micrometer) fine metal screen. The total opening area in the perforated square tube is 0.615 ft^2. One end (the bottom) of the square tube is closed. The other end of the square tube is open and is welded to a 3/4-inch diameter, 8-inch long stainless steel threaded tube. The filter element is suspended from the top flange. The distance between the bottom of the filter element to the gas distributor can be varied from zero to a maximum of 6 inches by positioning the filter element at different heights. Gas flows into the bed through a gas distributor and exits the bed through the metal-screen and the holes in the two sides of the filter element.

Bed material of two different densities was used in the experiments: 30 x 270 mesh acrylic powder with particle density of 1.10 g/cm^3 and -40 mesh sands with particle density of 2.5 gm/cm^3. During the operation, 3.8 gm/min (0.5 pounds/hr) of fine sands, which is less than 100 micrometers were continuously fed through a powder feeder into the bottom of the fluidized bed. The powder feeder consists basically of a stainless steel canister mounted upon a vibrating unit. A miniature, variable-speed screw conveyor in the bottom of the canister carries the powder to a mixing carburetor where the powder is entrained by the carrier gas. The powder feeder is rated for operation up to 100 psig pressure and is able to feed 0.5 to 5 pounds of fines per hour. Coarse bed material (either acrylic powder or sand) was fed continuously into the bottom of the fluidized bed through a non-mechanical "L" valve. In order to maintain a constant bed level, the same amount of bed material and fines were withdrawn continuously from the fluidized bed through an overflow tube to a loop seal. These coarse bed material and fines were, then, transported to a solid collection vessel for reuse or disposal.

Pressure transmitters were used to measure the pressure differentials as well as to characterize the hydrodynamics of the fluidized-bed filtration process. As illustrated in Figure 4, three high-speed (125 samples/sec) differential pressure transmitters were used. The PDT-57 transmitter measured the pressure differentials and the differential pressure fluctuations across a 4-inch bed. The differential pressure drops and the differential pressure fluctuation across the fluidized bed were measured with transmitter PDT-58. PDT-59 transmitter measured pressure drops across the entire system, which included pressure drops across both the fluidized bed and the filter element.

Solid loading in the gas stream was measured downstream of the filter element with a Particle Counter-Sizer-Velocimeter (PCSV), which was an on-line, laser-based particle monitor. The PCSV operates on the principle that the light scattered by single particles moving through the sample volume of a focussed high intensity laser beam. The PCSV is capable of sizing particles from 0.2 micrometers to 200 micrometers.

RESULTS AND DISCUSSION

In order to demonstrate the technical feasibility of the fluidized-bed granular filtration concept, a two-dimensional cold model was designed and constructed. During the initial phase of the exploratory testing (the purpose of these tests is to determine the reproducibility in performance data as well as to explore the limitations of the system), it was found that the density of the bed material is critical to the formation of the granular layer at the surface of the filter element and, thus affecting the performance of the granular filtration in fluidized bed. Two different bed materials, acrylic powder and sand were chosen to investigate the effect of bed material density on granular filtration performance.

Figure 5 shows the granular filtration performance in the fluidized-bed at the operating conditions listed below. The PCSV measured cumulative size distributions of dust loadings downstream from the filter element at different data measuring periods are plotted against particle size in this figure. The data measuring period is defined by the preset total particle counts on the PCSV (in the present case the preset number of particle counts is 5,000). In this test, dust penetrated through the filter element reaching a high concentration ranging from 4.2 x 10^3 particles per cm^3 to 1.1 x 10^5 particles per cm^3. Visual observation through the Lexan windows showed that filter surface immersed in the fluidized bed was clean and very little bed material was held against the screen. The heavy bed material and its vigorous scouring motion prevented deposition of fine particles on the surface of the filter element. Without the proper thickness of a granular layer as filtration media, particles smaller than the screen size eventually penetrate through the filter element and escape. The poor filtration performance, therefore, is primarily attributed to the failure to maintain a granular layer, that is, keeping sufficient filtration media at the surface of the filter element.

TABLE 1. EXPERIMENTAL CONDITIONS FOR TEST NO. SS05

Bed Material: Millwood Sands
Bed Material Size: 420 x 0 micron
Fines: Millwood Fine Sands
Fine Sand Size: < 100 micron
Fine Sand Feed Rate: 3.8 gm/min (0.5 lb/hr)
Distance to Filter: 0.152 m (6 inches)
Static Bed Height: 0.254 m (10 inches)
Gas Flow Rate: 3.68 and 6.51 m^3/hr (130 and 230 scfh)

It is also of interest to show that 90 percent of the particles which penetrated the filter element were fines with have sizes less than 3 microns. Table 2 shows that only 0.1 percent of large particles having sizes between 40 to 149 micrometers were able to penetrate through the filter element. This suggests that a very thin granular layer may still deposit at the surface. As a result, void spaces in the granular layer have been reduced. As a particle approaches the thin granular layer, it will either strike one or more surface particles or enter a void space. If the particle is larger than the void it attempts to enter, the particle will be "sieved" out. The reduction of void size in the thin granular layer, thus, "sieved" out most of the particles having sizes larger than 40 micrometers. If the particle is smaller than the void it enters, it will continue traveling through the void until it touches the particle surface and adheres; or until the particle passes through the void and the screen opening and exits on the clean air side of the filter element. Particle penetration, therefore, depends both on the thickness and packing density or permeability of this granular layer. Based on the experimental data, the thin granular layer formed with the heavy sand particles at the surface of the filter element does not provide sufficient thickness and packing density to filter out the fine particles. As a consequence, large amount of fine particles can still penetrate through the thin granular layer deposited at the surface of the filter element.

TABLE 2. CUMULATIVE NUMBER CONCENTRATION FOR TEST NO. SS05, DATA COLLECTION PERIOD N04

%	Diameter	Cum Numb Conc
99.90	0.50	1.1E+05
99.00	0.50	1.1E+05
90.00	0.53	1.0E+05
70.00	0.65	7.8E+05
50.00	0.79	5.6E+04
30.00	1.03	3.3E+04
10.00	2.22	1.1E+04
1.00	8.06	1.1E+03
0.10	37.08	1.1E+02

Figure 6 shows filtration performance under a different set of operating conditions listed below. A major difference in experimental conditions for Test SA06 is that lighter bed material was used in this experiment. The acrylic powder has particle density of 1.1 gm/cm^3 which is less than half of the density of the heavy sand particles. Figure 6 shows the in-line PCSV measurements of dust penetration through the filter element. Cumulative particulate concentration measured at down stream of the filter element was plotted against particle sizes. Solid loadings in gas stream ranging from 10^2 number per cm^3 to 10^3 number per cm^3 were measured. As can be seen from these data, the acrylic bed material provides a much better filtration performance. The acrylic powder fluidized bed, though provides certain turbulent motion for scouring and cleaning, however, such motion is not sufficient to remove the entire deposit layer (since the solid is much lighter and, therefore, has less momentum to scour and clean the surface). A fairly thick granular layer, approximately 2 cm thick can be maintained at the immersed filter surface as this can clearly be observed through the transparent windows. This deposit layer provides sufficient thickness and high packing density in comparison to heavy bed material. As a consequence, the permeability of the deposit layer was low, thus restricting dust particle penetration through the loaded filter media.

TABLE 3. EXPERIMENTAL CONDITIONS FOR TEST NO. SA06

Bed Material: Acrylic powder
Bed Material Size: 595 x 53 micron
Fines: Millwood fine Sands
Fine Sand Size: < 100 micron
Fine Sand Feed Rate: 3.8 gm/min (0.5 lb/hr)
Distance to Filter: 0.152 m (6 inches)
Static Bed Height: 0.352 m (10 inches)
Gas Flow Rate: 3.68 and 9.34 m^3/hr (130 and 330 scfh)

The increase in particle penetration through the filter element during data collection period N03 may be attributed to the change of quality of fluidization as more and more fine sand were added to the bed. When the fluidized bed saturated with fine sands, the bed density increases and the air can no longer evenly distribute through the gas distributor. Instead, the air forms a center jet and the chain of bubbles which form at the top of the center jet impinge on the filter. This exerts a higher pressure on the lower portion of the filter element and causes higher particle penetration through the granular layer. As shown in Table 4, however, the low permeability of the deposit layer for acrylic powder limited the size of the largest particle that can penetrate to less than 33 micrometers and its total number of penetration through the filter element to 0.1 percent.

Both the data from Test Nos. SS05 and SA06 were plotted in Figure 7 in terms of particle loading in parts per million by weight. For the heavy sand particles, the gas velocity was not capable of maintaining a proper thickness of a granular layer,

TABLE 4. CUMULATIVE NUMBER CONCENTRATION FOR TEST NO. SA06, DATA COLLECTION PERIOD N03

%	Diameter	Cum Numb Conc
99.90	0.66	9.4E+02
99.00	0.66	9.3E+02
90.00	0.70	8.5E+02
70.00	0.92	6.6E+02
50.00	1.47	4.7E+02
30.00	1.97	2.8E+02
10.00	2.86	9.4E+01
1.00	16.96	9.4E+00
0.10	32.98	9.4E-02

particles smaller than the metal screen opening penetrate through the filter element. The rise in particle penetration through the filter element with time is caused by the removal of the granular layer. During Test SS05, a small amount of acrylic powder was fed initially into the system prior to bed material. This was done to deliberately deposit a layer of filter media on the filter surface. It was believe that such a layer could be maintained to provide good filtration performance even when heavy bed material is added to the system later. However, these data show that the turbulent motion of the heavy bed material removes the granular layer of acrylic powder quickly and particle penetration through the filter element, thus, increases dramatically. For the acrylic powder, however, filtration performance was improved and particle penetration was greatly reduced from 106 to 8 ppmw. The packing density and the thickness of the granular layer maintained at the surface of the filter element was sufficient to provide high filtration performance.

Overall Filter collection efficiency was plotted for both heavy and light bed materials in Figure 8. High filter collection efficiencies, above 99 percent were obtained for acrylic bed material in Test No. SA06. Slightly lower efficiencies at higher gas velocities, Test Period N01 and N03, are observed from these data. Increasing gas velocity creates two counter effects on the structure of the granular layer. It increases the packing density in the granular layer and as a consequence, lowered the permeability and reduced particulate penetration through the granular layer. However, higher gas velocity also exerts higher pressure to the particles in the granular layer. The fine particles closed to the metal screen become compressed and start passing through the screen.

FUTURE WORK

Based on the preliminary data, the fluidized-bed granular filter provides an alternative concept for particulate cleanup. The fluidized-bed granular filtration concept offers a more reliable, simpler, and economical particulate control system for hot gas-stream cleanup. However, these preliminary data show that for heavy bed material, the filtration performance suffers greatly due to the failure of maintaining a sufficiently thick granular layer at the screen surface of the filter element. A modified metal screen filter was tested in the two-dimensional fluidized bed cold model. Preliminary filtration performance of this modified filter showed high collection efficiency for both light and heavy bed materials. However, no information is provided in this paper as patent application for the modified filter is currently being filed. Future activities in the program will concentrate on testing of this modified filter in the fluidized-bed granular filtration cold model. More specifically, the development of the granular layer at the surface of the filter element and its influence on the quality of fluidization, effect of filtration media on the structure of the granular layer, and the behavior and holdup of fine dust in the bed and in the granular layer will be studied in the two-dimensional cold model as well as a three-dimensional cold model to be constructed next year. In addition, a two- to three-tube configuration will also be explored. The purpose of this program is to provide an optimum configuration for the future design of a hot fluidized-bed granular filtration system.

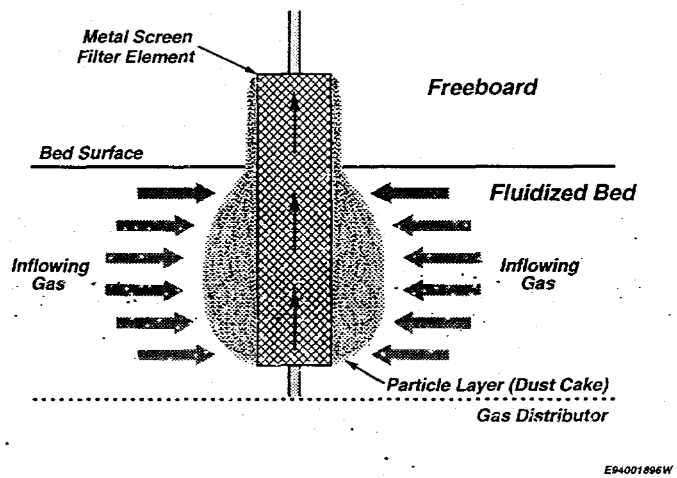

FIGURE 1. FLUIDIZED-BED GRANULAR FILTRATION CONCEPT

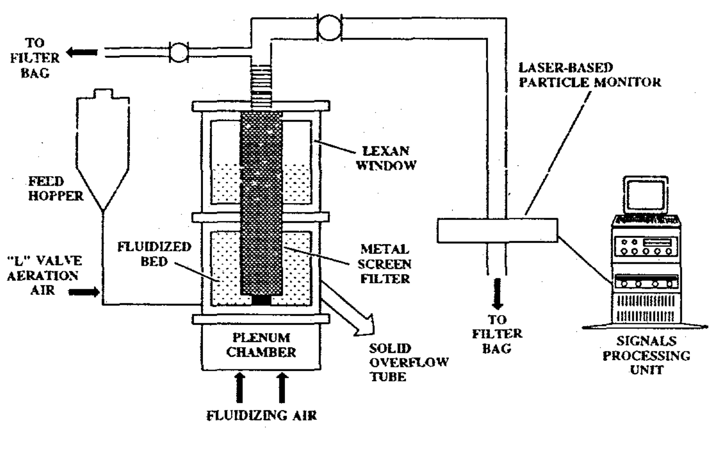

FIGURE 2. SIMPLIFIED PROCESS FLOW DIAGRAM FOR THE TWO-DIMENSIONAL FLUIDIZED-BED GRANULAR FILTRATION COLD MODEL

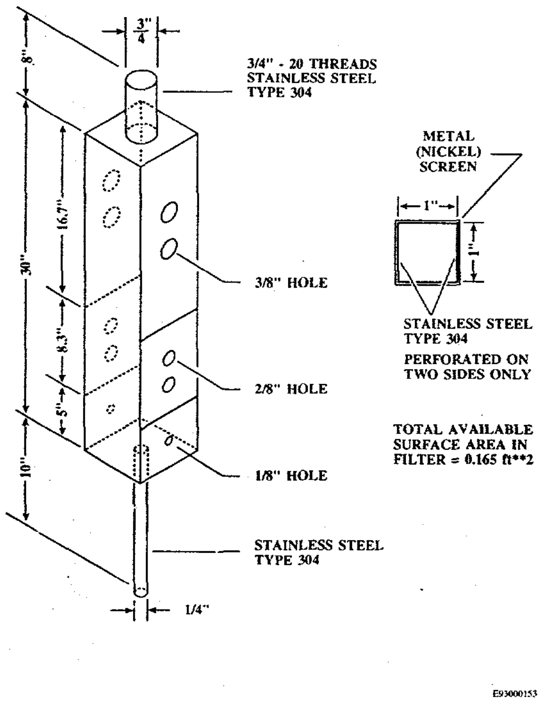

FIGURE 3. METAL SCREEN FILTER ELEMENT

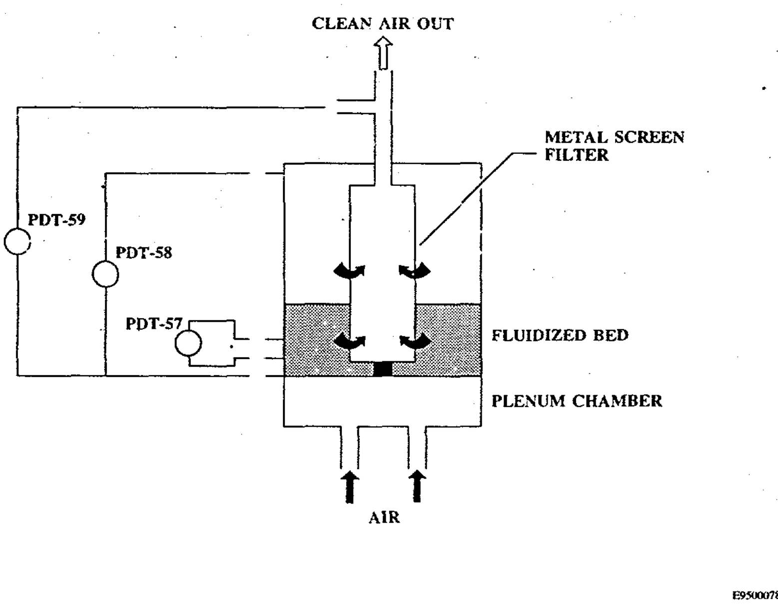

FIGURE 4. SCHEMATIC DIAGRAM FOR THE LOCATION OF PRESSURE TRANSMITTERS IN THE TWO-DIMENSIONAL FLUIDIZED-BED GRANULAR FILTER COLD MODEL

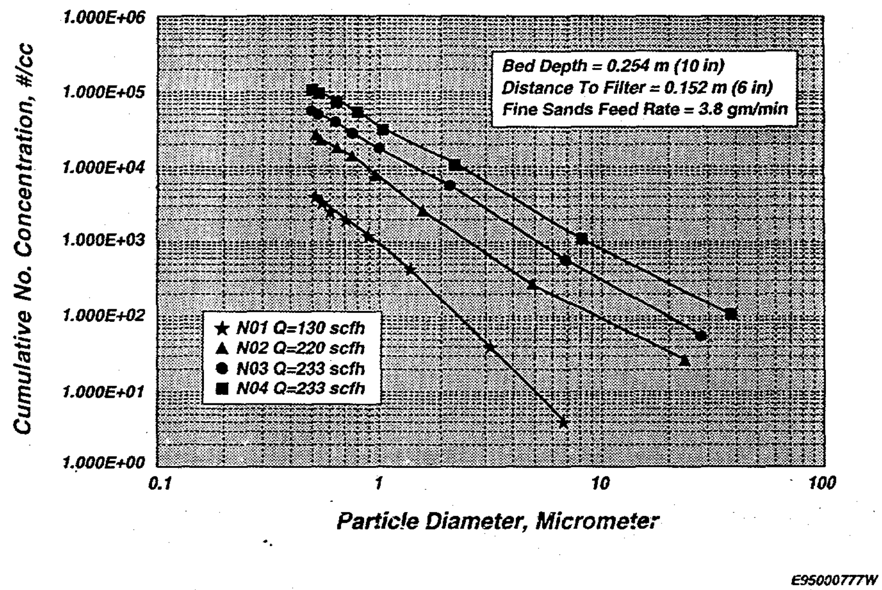

FIGURE 5. PARTICLE PENETRATION THROUGH FILTER ELEMENT, TEST NO. SS05 -40 MESH MILLWOOD SAND

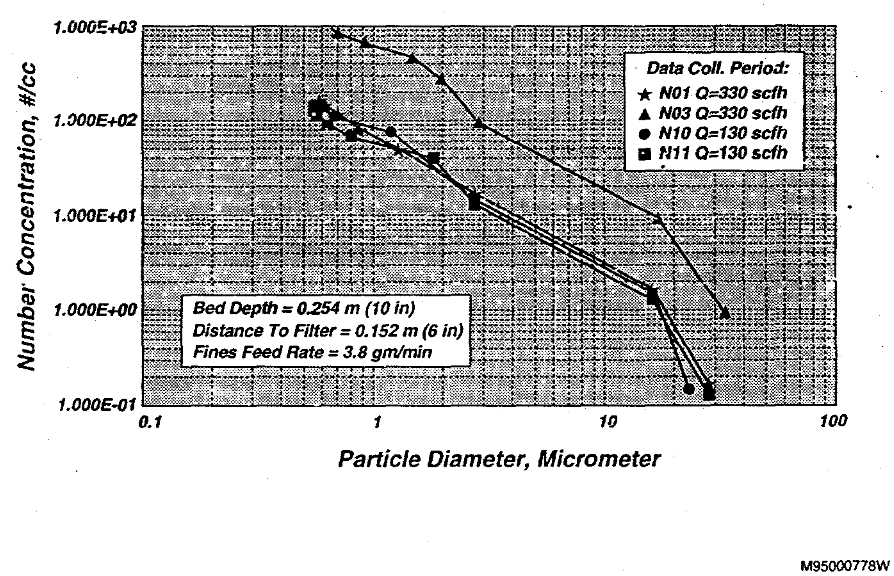

FIGURE 6. PARTICLE PENETRATION THROUGH FILTER ELEMENT, TEST NO. SA06 30 X 270 ACRYLIC POWDER

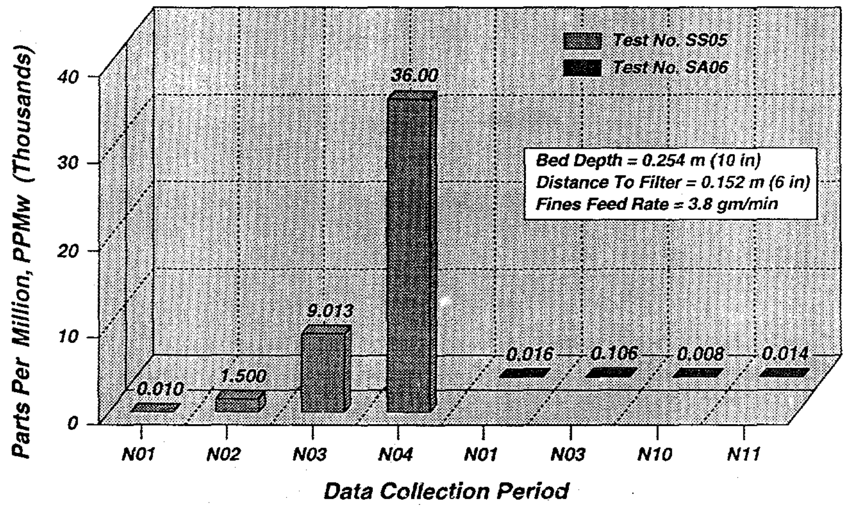

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FIGURE 7. PARTICLE PENETRATION THROUGH FILTER ELEMENT.
TEST SA06: ACRYLIC POWDER AND FINE SANDS.
TEST SS05: COARSE AND FINE SANDS.

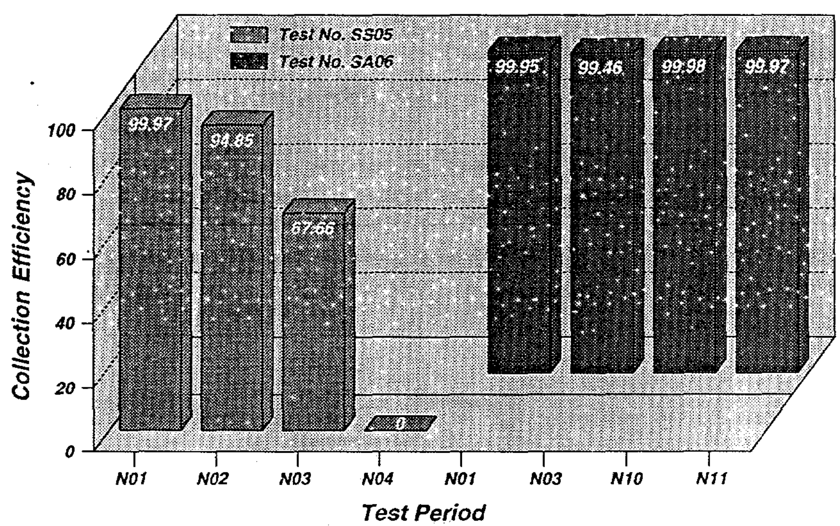

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FIGURE 8. FILTER OVERALL COLLECTION EFFICIENCY
TEST SA06: ACRYLIC POWDER WITH FINE SANDS.
TEST SS05: COARSE AND FINE SANDS.

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