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GAS SOLIDS SEPARATION USING SINTERED POROUS METAL TECHNOLOGY

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Gas Solids Separation using Sintered Porous Metal Technology

Abstract

When selecting industrial process equipment for gas/solids separations, one can choose from several different technologies. Options range from gravity settling to electrostatic precipitation. Each has its own degree of effectiveness and cost. In applications where high removal efficiency is critical, filtration has no equal. The reason for this is simple. Compared to other methods, filtration is the only one which provides a positive barrier between the process and the "solids free" stream.

Sintered porous metal filter media offers unique performance characteristics for gas/solids separation. Precision porous metal media, with its precise bubble point control, and excellent uniformity of permeability assures reliable filtration performance, effective blowback cleaning and long on-stream service life.

Extended testing provided data relevant to the trends of performance efficiency and indicated desirable rates of operation. Recovery pressure drop after blowback was examined for long term trends at different flow velocities. Optimum operating conditions were determined for long operating life.

Data are presented for challenge tests using monodisperse sodium chloride aerosols using 2, 5, and 10 µm sintered porous metal media. Continuous process filtration testing was evaluated using filter elements with 2, 5, and 10 µm media at forward flow velocities of 4, 6, 8, and 10 feet per minute in the filtration of power plant flyash from air using the Mott HyPulse® GSV Filter System. Particle penetration into the porous wall was examined by scanning electron microscopy and energy dispersive x-ray analysis and is related to forward flow velocity.

Introduction

Filtration systems utilizing sintered metal media have proven to be an effective and economical alternative to other separation equipment susceptible to pressure spikes, high temperatures, and aggressive environments. This includes bag houses, cyclones, electrostatic precipitators and scrubbers. Sintered metal media has demonstrated high efficiency particle removal, reliable filtration performance, effective blowback cleaning and long on-stream service life in many industrial applications utilizing calciners, incinerators and fluid bed dryers. Sintered metal media is well suited for dust removal and gas treatment, particularly where hot gasses and sparks are present.

New governmental regulations have imposed tighter limits on the quality and quantity of gaseous emissions to atmosphere.[1] Bag filters are limited by the physical and chemical properties of the fabric medium, which in general forms cannot withstand high temperatures or corrosive atmospheres.[2] The frequent and costly bag filter problems with fires, solids breakthrough and media replacement are eliminated using sintered metal media.

Sintered metal has proven performance in the recovery of catalysts, products for chemical processing and pharmaceuticals applications, rock quarries, metal mining industry, power generating facilities, coal and coke handling operations, and many other applications.

Principle Features, Properties and Uses of Sintered Metal Media for Gas/Solids Separation

Customers and processes are demanding finer filtration at all levels, along with more reliable filter media. Sintered porous metal media meets this criteria and offers high removal efficiency to meet tighter emission standards for today's industrial applications. The development of specially designed and engineered sintered porous metal media with a stable porous matrix, precise bubble point specifications, close thickness tolerances, and uniformity of permeability assures reliable filtration performance, effective blowback cleaning and long on-stream service life.

Construction of sintered media can be tailored for specific applications. Sintered metal media can be made from various alloys that are suited for both corrosive and high temperature applications. Precise furnace atmosphere control, sintering temperature control, and time at temperature assures “solids state diffusion bonding” at every contact point between adjacent particles in the porous structure.

This permanent structure allows filter cartridges to be cleaned in several ways with no media migration. In-situ cleaning in process filters is by blowback. Chemical cleaning with compatible materials, or ultrasonic cleaning in a detergent solution will remove insoluble contaminants from the filter.

Corrosion Resistant Alloys
Porous metal media is available in a wide variety of corrosion resistant alloys including: Stainless Steel 316 L , 304L, 310, 347, and 430; Hastelloy B, B-2, C-22, C276, N and X; Inconel 600, 625, and 690; Monel 400; Nickel 200; Alloy 20; Titanium.

High Temperature Capability
Sintered porous metal offers a temperature range of 750 to 1750°F depending on alloy material and atmospheric conditions as indicated in Table 1. Temperature limitations of sintered porous metal in an oxidizing environment are not due to strength of material, but due to oxides which form at elevated temperatures. The specific void volume of the oxide is much greater than the parent metal, which results in plugging of the pores in the media. In a reducing or neutral atmosphere, temperature limitations are due to strength of the material at elevated temperatures.

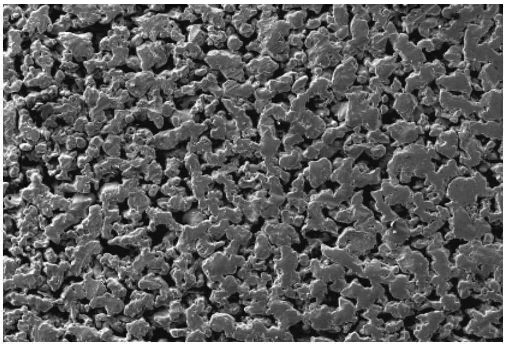

Figure 1. Micrograph of 316L stainless steel 2 μm media (100 x magnification).

Table 1
Max. Temperatures using Sintered Metal

Material	Oxidizing	Reducing
316 L SS	750° F	1000° F
310 SS	1100° F	1500° F
Inconel 600	1100° F	1500° F
Hastelloy X	1450° F	1750° F

High Differential Pressure Capability
Porous metal filter elements can be supplied to withstand differential pressures over 3000 PSI. Sintered metal is permanent media with an all welded construction. The media can withstand pressure spikes with no evidence of media migration.

Available Pore Size
Porous metal is available in media grades 0.2, 0.5, 1, 2, 5, 10, 20, 40 and 100 μm media. Choice of media grade is determined by required flowrate and filter performance specifications.

Process Filter Considerations

There are two basic process designs of gas/solids filtration systems and both designs are well suited for sintered porous metal cartridges: Final or trap filters, and continuous process filters. In their typical operating mode, both designs work in a similar fashion, gas flows through the media and solids are retained and accumulate on it. The fundamental difference between the two is the frequency and method of solids removal and element regeneration. The decision on which type of filter to employ depends on individual process parameters, primarily the solids loading in the feedstream.

Final or trap filters are used on basically clean streams where the objective is either polishing or protection of downstream processes and equipment. These filters are not intended for in-situ cleaning and solids removal requires disassembly. Elements are normally cleaned externally using chemical or ultrasonic methods. The interval between cleaning varies with the solids load and the feed gas.

A continuous process filter is ideally suited for heavily laden streams or in processes containing hazardous materials. Again, the cleaning or blowback interval depends on the solids loading. Typical periods range from 1 to 2 minutes up to many hours. The blowback cycle can be initiated either manually or automatically based on time lapse or differential pressure.

Mott Corporation offers two different continuous process filter designs, the HyPulse GSP (Gas-Solids-Plenum) and the HyPulse GSV

(Gas-Solids-Venturi). Both systems are well suited for automated process control and include in-situ cleaning for the elements but in somewhat different ways.

Dirt loading on the filter elements is similar for both filter configurations. During the filter cycle, the gas/solids mixture enters the unit and flows toward the outside of the sintered metal cartridge filters, where solids are retained. Clean gas passes through the element wall to the plenum chamber and is discharged.

Blowback Cleaning the HyPulse GSP Filter System (Plenum): Upon reaching a given differential pressure or cycle time, the feed is discontinued and the backflow cycle begins. The filter is isolated and gas enters the gas inlet. Reverse flowing through the plenum chamber and elements discharges the cake from the element wall as shown in Figure 2.

Blowback Cleaning the HyPulse GSV (Ventui-pulse) Filter System: This system delivers high throughput with minimum backpulse gas requirements. Sintered metal cartridge filters

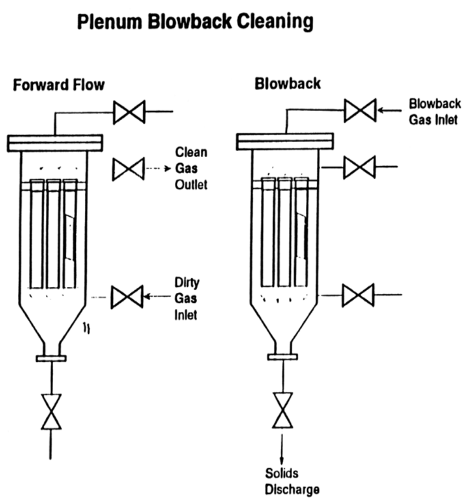

Figure 2. Mott GSP filter schematic diagram.

are manifolded together and backpulsed sequentially while the unit remains on-line.

When a predetermined differential pressure or cycle time is realized, the elements are backpulsed to remove the cake. While on-line, a burst of high pressure gas enters the nozzle manifold through the upstream solenoid valves. The blowback gas exits the nozzles and enters the venturis entraining the gas from the plenum chamber. The resulting gas flow creates a high energy backpulse on the elements that lifts off the filter cake. The cake falls into a discharge hopper and is removed.

The case study discussed in this paper involves the removal of flyash from air using the Mott HyPulse GSV filter system.

Filtration Mechanisms

The ability of a filter to remove particles from the gas stream passing through it is usually described in terms of penetration or collection efficiency. Basic capture mechanisms apply to clean or new sintered metal filters in initial cycles. The structure of sintered metal provides a tortuous path in which particles are captured. Particle capture via these mechanisms continue as a cake of deposited particles is formed on the media surface, however, particles are now captured on previously deposited particles. The relationship between these parameters and the particle size both upstream and downstream of the filter is:

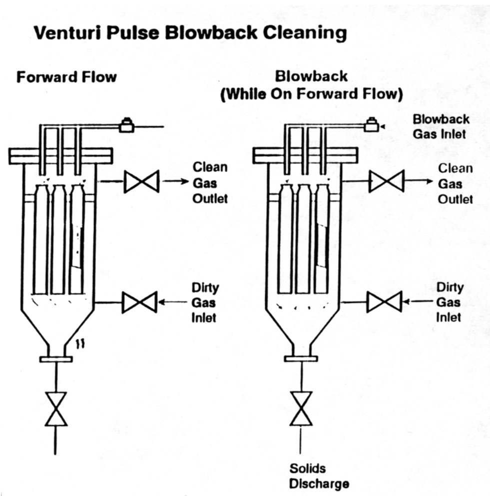

Figure 3. Mott GSV filter schematic diagram.

Penetration = 1- collection efficiency

$$= \frac{\text{downstream particle concentration}}{\text{upstream particle concentratrion}}$$

Figure 4 illustrates the resulting particle penetration as a function of the particle. For particles in the vicinity of the most penetrating particle size, the dominant particle collection mechanisms are diffusion and interception. The effect of the particle size on particle capture via each of these mechanisms is shown. The combination of these two mechanisms leads to an overall particle penetration curve that first increases with increasing particle size, then decreases with further increases in the particle size. Of particular importance is the maximum in this curve. This is referred to as the maximum penetration which is also the point of minimum particle capture efficiency. The corresponding particle size is referred to as the most penetrating particle size. Larger particles are captured via interception and inertia impaction mechanisms.

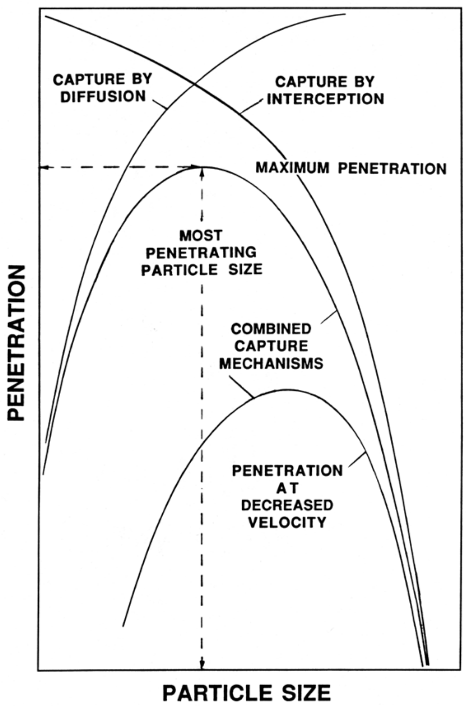

Figure 4. The effect of particle capture mechanisms and flowrate (face velocity) on penetration.

The effect of gas flow rate through the filter on particle penetration is also illustrated in Figure 4. The maximum penetration decreases as the gas flow rate is decreased with a slight increase in the most penetrating particle size. The particle penetration for all filter materials exhibit the basic shape shown in Figure 4. The level of penetration and the location of the most penetrating particle size depends on the filter and its usage.

Face velocity is an influencing factor in particle capture. A filtration system is designed to limit forward flow or face velocity to achieve long on-stream life operation and prevent particle intrusion into the media. A filter design which exceeds the maximum face velocity can lead to premature blinding of the filter element(s). Gas filtration performance is enhanced when a surface or cake is formed providing additional long term filtration.

Fractional Penetration Tests

Tests were performed using monodisperse sodium chloride aerosols in the 0.03 to 0.8 µm range, produced by electrostatic classification of polydisperse aerosol obtained by atomization. The challenge tests were performed to minimize particle loading in order to ascertain the particle penetration through clean filter media. Particle capture (collection efficiency) is known to increase with particle loading. Aerosol concentrations upstream and downstream of the filter were measured simultaneously with CNC's (Condensate Nucleus Counters).

Fractional particle penetration for sintered metal media grades 2, 5 and 10 µm were performed at airflows of 2, 8, and 16 SCFM/ft^2. The results are summarized in Table 2. The graphs are shown in Figures 5-7. At each velocity, the maximum penetration and most penetrating particle size increase with increasing pore size rating, however the basic shape of the curves are all similar.

Table 2
Particle Penetration Characteristics of Clean 316L Stainless Steel Sintered Porous Metal Media

Media Grade, µm	Airflow scfm/ft^2	Most Penetrating Particle Size, µm	Max Fractional Penetration
2	16	0.22	3.6 e-1
	8	0.28	2.5 e-1
	2	0.40	9.7 e-2
5	16	0.25	5.6 e-1
	8	0.30	4.9 e-1
	2	0.45	3.0 e-1
10	16	0.30	7.9 e-1
	8	0.35	7.5 e-1
	2	0.50	5.6 e-1

For the largest particle sizes, the penetration curves at an airfow of 16 SCFM/ft^2 are lower than those obtained at the lower air flow rates due to enhanced particle collection via the inertial impaction mechanism. This mechanism becomes dominant for the larger particle sizes at higher flowrates. [3]

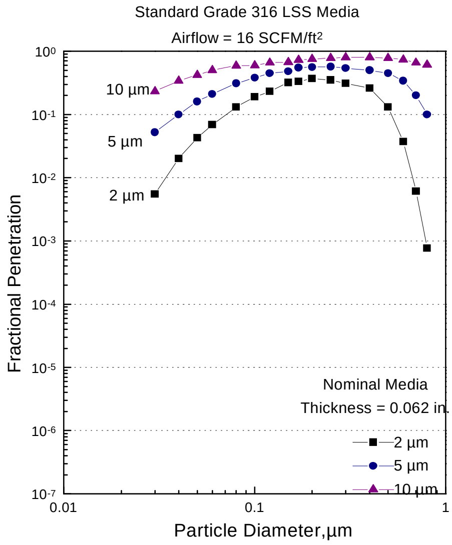

Figure 5. Fractional penetration at airflow of 16 SCFM/ft^2.

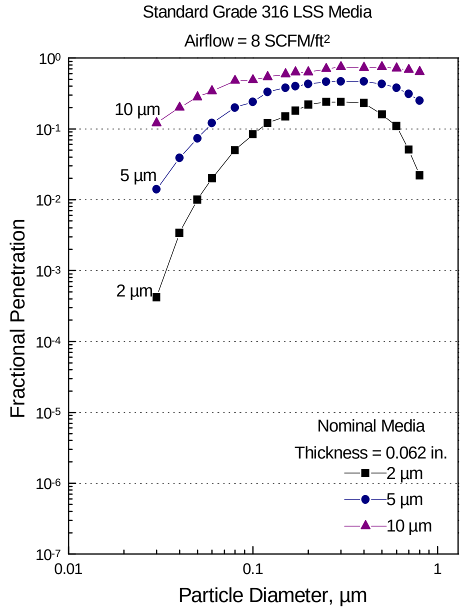

Figure 6. Fractional penetration at airflow of 8 SCFM/ft^2.

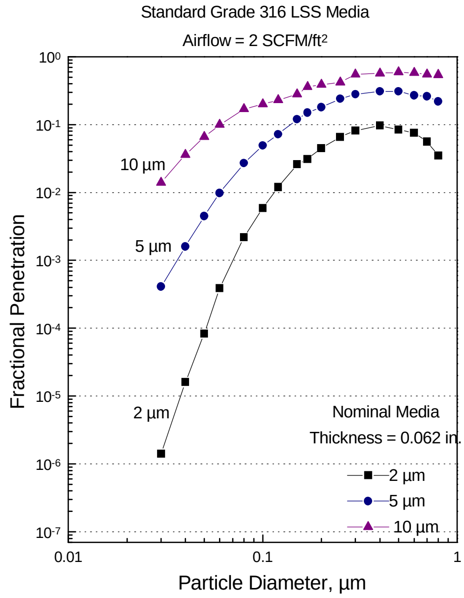

Figure 7. Fractional penetration at airflow of 2 SCFM/ft^2.

Case Study: Continuous Process Filtration using Sintered Metal Media and Fly Ash Contaminant in Ambient Air

Objective

Sintered porous stainless steel filter elements were evaluated in the filtration of flyash contaminant in ambient air using a pilot scale continuous process filter. Grades 2, 5, and 10 µm 316L stainless steel sintered metal media were evaluated at approach velocities of 4, 6, 8, and 10 ft/min. Clean flow pressure drop versus forward flow velocity is shown in Figure 8. The filter was cleaned in-situ using venturi pulse blowback and demonstrated that equilibrium recovery differential pressure is a function of gas approach velocity, and is associated with an exponentially diminishing concentration gradient of flyash subsurface cake. Stable recovery differential pressure equilibrium was achieved within 25 cycles at low velocities. Dynamic subsurface cake formation is shown to penetrate the filter medium wall less than 0.03 inches using SEM photography and EDX analysis.

Porous Metal Media

Filter media were Mott sintered type 316L stainless steel powder metal, with filter ratings of 2, 5, and 10 µm, having bubble points in isopropyl alcohol of 20, 15, and 9.5" water pressure, respectively. Tensile yield strength at 0.2 percent offset was 21,100; 15,200 and 11,900 PSI, respectively. Modulus of elasticity was 7.8, 5.1 and 4.9 x 10^6. Ambient air flow at 4 SCFM/ft^2 or 4 ft/min approach velocity, produced differential pressures of 3.0, 1.6, and 0.6 inches of water, respectively. These characteristics are typical for production materials.

Flyash Test Contaminant

Particle size distribution was determined using a Coulter counter. The frequency histogram shows no particles larger than about 120 µm, with fairly uniform logarithmic distribution to below about 2.5 µm. Median particle size is about 12 µm diameter. Chemical analysis showed substantial calcium content, which was used as a tracer element for later EDX analysis to determine filter medium wall penetration by flyash.

Continuous Process Gas Filtration Test System

The test stand consisted of an air supply system, a flyash feed system, filter housing assembly with various filter elements, appropriate instrumentation for measurement of air flowrate and pressure drop, and an aerosol monitor for checking effluent air cleanliness.

The air supply from plant air compressors was filtered in three stages to less than 0.5 µm and dried with silica gel desiccant. A negative ion generator was used to minimize electrokinetic effects and static electricity associated with the dry air stream flow. An accumulator and pressure regulator provided steady-state supply.

The flyash feed system consisted of a combination dual auger feed and eductor dispersion device. Flyash was fed by variable speed auger through the bulk-supply funnel to a second metering auger, and finally to the eductor suction inlet. The full test supply air was introduced through the eductor which also served to disperse the flyash feed and provide uniform contaminant loading for the air.

The filter housing was fabricated from transparent acrylic plastic, to allow direct visual observation of filtration and blowback, and accommodated a maximum of 6 filter elements with an associated verturis, solenoid valve manifold, and blowback control system. A side-port probe allowed direct measurement of flyash cake thickness on the filter elements. Blowback flyash was collected and weighed in a bottom receiver to provide a material balance check on flyash feed.

Instrumentation included a rotometer measurement of eductor air flow and a sharp-edge orifice meter for effluent air flow output. Differential pressures were measured with manometers connected to determine both housing-to-bonnet pressure drop and outside-to-inside filter element pressure drop. A forward scattering photometric aerosol monitor and recorder was used to measure effluent air cleanliness after filtration.

Gas Filtration Test Program

Gas filtration tests were conducted with 2, 5, and 10 µm filter elements at apparent approach air flow velocities of 4, 6, 8, and 10 feet per minute. Most tests consisted of 25 blowback cycles, except for two test series at 10 ft/min (FPM) where plugging became apparent after only 5 cycles. A total of 260 blowback test cycles were run. Measurements included differential pressure for both housing to bonnet and element wall before and after blowback. Figures 9 to 11 show cake thickness versus pressure drop for 2, 5, and 10 µm media.

Cake thickness was measured by probing before blowback and averaged about 0.1 inches for most tests. Cake density was determined by calculation of cake volume and weight. Weighing of flyash in the bottom receiver before and after blowback provides a check on flyash/air loading concentration which averaged 0.25 grams/ft^3 for most tests.

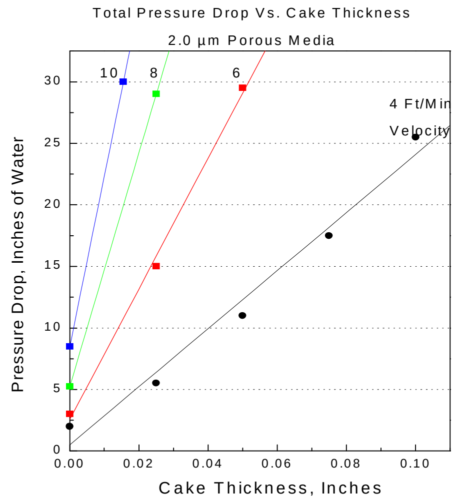

Figure 9. Total pressure drop vs. cake thickness for 2 µm sintered porous media.

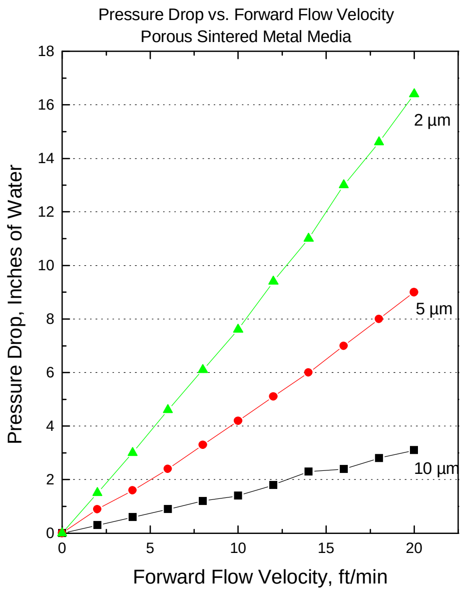

Figure 8. Clean flow pressure drop vs. forward flow velocity of sintered porous media.

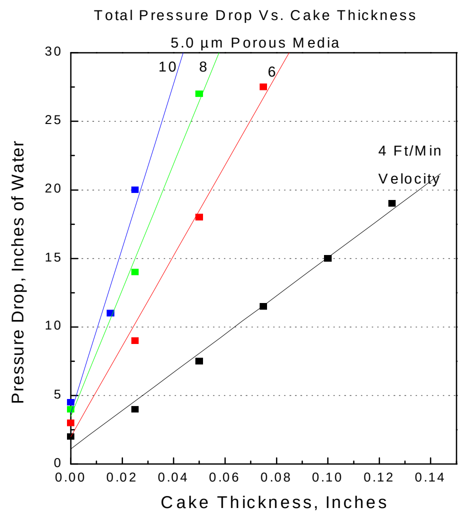

Figure 10. Total pressure drop vs. cake thickness for 5 µm sintered porous media.

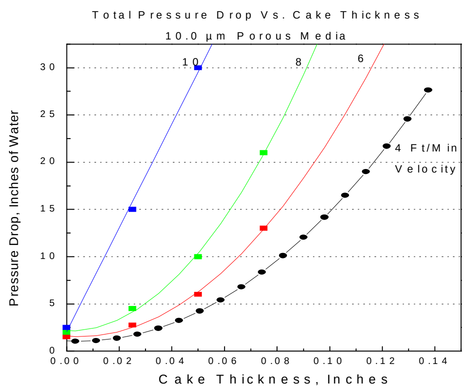

Figure 11. Total pressure drop vs. cake thickness for 10 µm sintered porous media.

Table 3
Recovery Pressure Equilibrium

Media Grade, µm	Pressure Drop, Inch water, at Face Velocity, ft/min: 4	6	8	10
2	3.0	6.8	5.3	*
5	3.0	6.6	6.1	*
10	0.72	7.5	6.9	*

* No equilibrium in 25 cycles

Equilibrium recovery differential pressure within 25 blowback cycles was determined for each filter rating and air flow approach velocity combination. Results are summarized in Table 3.

Blowback Efficiency

The efficiency of blowback for the 25 cycle tests were calculated based on clean flow pressure drop at the flowing velocity, the average terminal pressure drop for the 25 cycles, and the mean recovery pressure drop for the last 5 cycles. The results are summarized in Table 4.

Table 4
GSV Blowback Efficiency

Grade, µm	Percentage of Clean Flow Pressure Drop Recovered Relative to Terminal Pressure Drop after Blowback at Face Media Velocity, ft/min: 4	6	8	10
2	89 %	82 %	90 %	-
5	88	71	85	83 %
10	96	81	80	-

Efficiencies are meaningful only for specific tests of operating parameters, and in this case the data are offered for comparison purposes. [4]

Particle Penetration

Particulate penetration of a filter element wall was determined by Scanning Electron Microscope (SEM) photography and Energy Dispersive X-ray (EDX) analysis based on detection of flyash calcium content. Subsurface cake formation extended through less than half of the wall thickness, about 0.060 inch. The results are summarized in Table 5 and Figure 13. Calcium content (flyash concentration) diminishes exponentially as a function of the wall thickness, and is not present beyond 0.030 inch depth in the 0.060 inch wall.

Table 5
EDX Calcium Analysis

Zone, inches	Ca Content, %
0.005	8.7
0.010	3.9
0.015	2.6
0.020	0.7
0.025	0.3
0.030	0.0

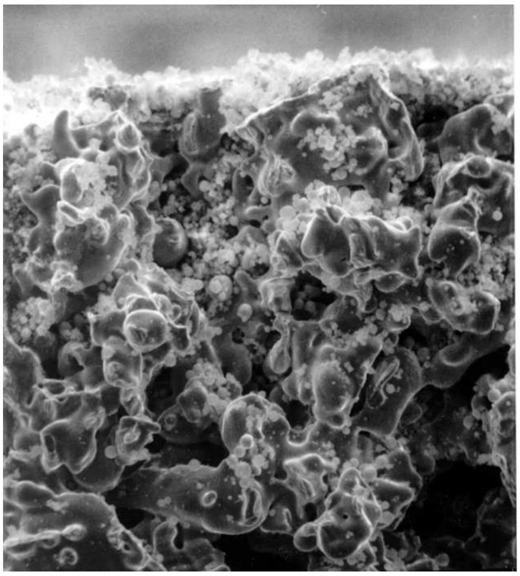

Figure 12. Micrograph of cross-section of 2 µm 316L media showing flyash penetration (300 x magnification).

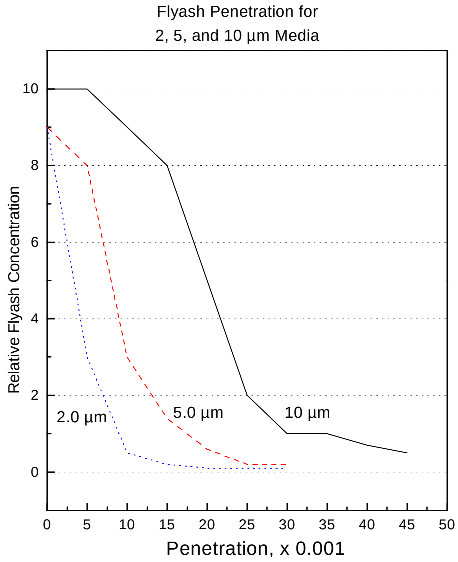

Figure 13. Flyash penetration for 2, 5 and 10 µm porous media.

Conclusions and Discussions

Sintered metal media is well suited for dust removal and gas treatment, particularly where pressure spikes, high temperatures, corrosive atmospheres, hot gasses and sparks are present. Filtration systems utilizing sintered metal media have been used successfully in place of bag houses, cyclones, electrostatic precipitators and scrubbers.

The operating conditions of a filter effect its useful life and impact the efficiency of blowback solids removal. There is a relationship of particle intrusion to media rating, particle characteristics, and design operating flowrate. particle intrusion media rating, particle characteristics, and design operating flowrate. Particulate penetration is an exponential function of the filter medium depth, and extended only to Particulate penetration is an exponential function of the filter medium depth, and extended only to one-half of the wall thickness for the medium that was tested.one-half of the wall thickness for the medium that was tested.

Both plenium blowback and venturi pulse blowback process systems are effective and can be designed to accommodate a wide range of applications and performance requirements. Recovery pressure equilibrium depends on both filter rating and approach velocity, and reaches apparent stability within 25 cycles at 4 to 6 ft/min. under specified test conditions.

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