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Self-Cleaning Metal Media HEPA Filter Technology and a Comparison with Glass Fiber HEPA Filter Media

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ABSTRACT

Traditional HEPA filter systems have limitations that may prevent them from solving some of the more onerous filtration problems in the nuclear industry; particularly in applications where long service or storage life, high levels of radioactivity, dangerous decomposition products, chemical aggression, organic solvents, elevated operating temperatures, fire resistance and resistance to moisture are issues. Many of these issues have been solved internationally by applying self-cleaning metal media filters to address HEPA filtration problems. Back flushable filters are used in conventional filtration systems to allow in-situ cleaning of the filter media, such that the filtration system can continue to operate without having to change the filter cartridge/bag. Standard HEPA filter cartridges are not designed to be back flushed as the pressure forces involved could damage the filter media. However, Porvair Filtration Group has developed a back-flushable HEPA filter technology that utilises porous metal media to provide the HEPA filtration capability and the structural stability that is needed to withstand the forces associated with the back flushing, or ‘pulse jet’ cleaning process. Pulse jet HEPA filters allow the HEPA filtration system to continue to operate without creating a secondary waste stream of spent HEPA cartridges. The use of self-cleaning metallic filter media HEPA systems are eminently suitable for nuclear decommissioning projects where large quantities of radioactive particulate are generated during dismantling and cutting operations, including situations where wet cutting techniques generate damp particulate and where the use of conventional HEPA filters would require frequent changing with the subsequent generation of a large volume of secondary wastes. The basic technology, development, performance characteristics, filtration efficiency, and cleanability of metal media HEPA filters is discussed in comparison with traditional resin bonded glass fiber filter media.

INTRODUCTION

The HEPA (High Efficiency Particulate Air Filter) represent a well-established and documented technology within the nuclear and wider industrial environment. Initially HEPA filters were developed for service gas mask use during the 1939-1945 world war, manufactured from materials such as esparto grass paper, asbestos wool and resin wool lap, these filters were crude by today’s standards both in terms of materials of construction and performance. Such filters were also increasingly utilized for the ventilation air of control rooms. During the 1950’s and 1960’s considerable improvements were made in filter papers improving filtration efficiency and pressure drop. These improvements focused initially on esparto grass paper followed by cellulose asbestos paper and glass fiber paper the later providing one of the base primary materials for today’s HEPA technology.

In parallel to the technological improvements so the definition of HEPA has developed and although the situation remains complicated by the number of different classification systems, test procedures and challenge aerosols utilized; e.g. ASME AG1, IEST, Eurovent/ CEN; the broad filtration efficiency and pressure loss characteristics are well defined.

Glass fiber media provides the base technology for HEPA filters within today's nuclear industry, randomly laid microfine glass fibers typically down to 0.3µm or less form the core structure of the media, strength is given to the fibers by using a resin binder and/ or laminating to a backing scrim. The glass fiber media is then typically sandwiched between upstream and downstream open spunbonded fiber.

Within the USA nuclear industry the requirement for glass fiber HEPA filters is well defined, ASME AG1-2003 "Code on Nuclear Air and Gas Treatment" fully defines the materials of construction, design, fabrication and inspection requirements for panel type filters and similar procedures are being developed for radial flow circular types.

The glass fiber HEPA filter is a well proven technology for the Nuclear Air Cleaning environment, microfine glass fibers result in a permeable filter medium highly efficient at collecting submicronic particles from the gas stream via Brownian motion (the random movement of very small particles due to bombardment by gas molecules). In addition it is very inert.

Limitations of MicroGlass Fiber HEPA Filters

While glass fiber media is clearly suitable for the majority of air cleaning/ ventilation applications, and the manufactures continue to develop and improve the material performance, such materials have a limited environmental envelope in which they can operate. High temperature, high humidity, water wetting, chemical degradation and mechanical robustness are environmental characteristics of many applications outside of standard ventilation conditions and the reliability of glass media under such conditions would give cause for concern.

Humidity

The presence of significant amounts of water collecting on the HEPA filter can cause the pores of the filter media to block and the pressure loss significantly increase, resulting in mechanical failure and loss of integrity within the media.

Temperature

The use of glass fiber HEPA filters is generally restricted to <250º F (ASME AG1 Section FC), limited by the breakdown in binders and resins and used in assembly. This prevents the use of such filters in applications such as incinerators, vitrification processes or results in filtration stage being performed at reduced temperature.

Environment Damage

Binders, resins, seals, etc are susceptible to radiation and acid damage.

Mechanical Strength

The mechanical strength of the filter media is a function of the fiber diameter, basis weight and binders used in the media construction.

Process fault conditions which can result in very high flow rates or high particulate loading resulting in significant increases in pressure loss across the filter media can result in structural damage to the HEPA filter and loss of integrity.

Metal Media Filtration

The technical issues discussed briefly above concerning the limitations of microfiber glass HEPA filters may lead us to question their reliability under fault conditions or ultimately exclude their use from many applications at high temperature such as venting fumes from incinerators, vitrification processes etc, or applications at high radiation as may be experienced during nuclear decommissioning projects.

However, clearly those technical limitations are exposed in a limited number of applications and microfiber glass HEPA's remain a well proven, documented, regulated and reliable product for the majority of applications.

Commercially, the life cycle costs of HEPA filtration systems from initial procurement, through installation, replacement, testing and disposal represent significant annual expenditure.

Cleanable metal media HEPA filter technology offers an alternative solution for air cleaning and ventilation systems that operate outside of normal HEPA operating conditions, and in applications where there is an incentive to reduce the secondary waste stream that would be created by the use of disposable HEPA filters.

Bergman et al presented in 1997, and Moore et al in 1992, a detailed analysis of the life cycle costs of a conventional glass fiber HEPA filter compared to a cleanable stainless steel HEPA.

Bergman et al concluded that the total DOE cost per year on glass HEPA filters was $29.5M based on an average life of 5 years and usage of 31,055 filters. He also proposed that stainless steel cleanable HEPA's could potentially reduce those life cycle costs by approximately $16.6M based on an average life of 30 years.

Much of the work presented in the 1990's focused on the development of cleanable HEPA filters manufactured from Sintered Metal Fiber or Sintered Metal Powder, however the industry remains slow to adopt the technology and there are many barriers to overcome with respect to validation and the incumbent risks associated with moving away from the proven technology.

Alternatively cleanable metal filters provide the potential to be installed as pre-filters to traditional HEPA filters to extend their life and provide protection from process fault conditions. This has the added advantage of retaining the proven release to atmosphere technology.

To overcome the limitations of microfiber glass media, sintered metallic media offers obvious advantages in terms of mechanical strength, temperature resistance, wet strength and chemical resistance.

Three main types of metal media exist, Sintered Metal Powder, Sintered Metal Fiber and Sintered Woven wire mesh. In addition to these composite structures of mesh/ fiber and powder/

mesh are also available. Sintered woven mesh is generally considered to filtration applications >10μm and not HEPA filtration.

Sintered Metal Powder

Sintered metal powder filters are manufactured from sieved metal powder; particles can be irregular or spherical in nature and typically in the size range 1-100 μm. The powder is laid as a flat sheet or loaded to a mold and pressed prior to sintering. The resultant porous media will have 30-50% porosity and be very mechanically robust.

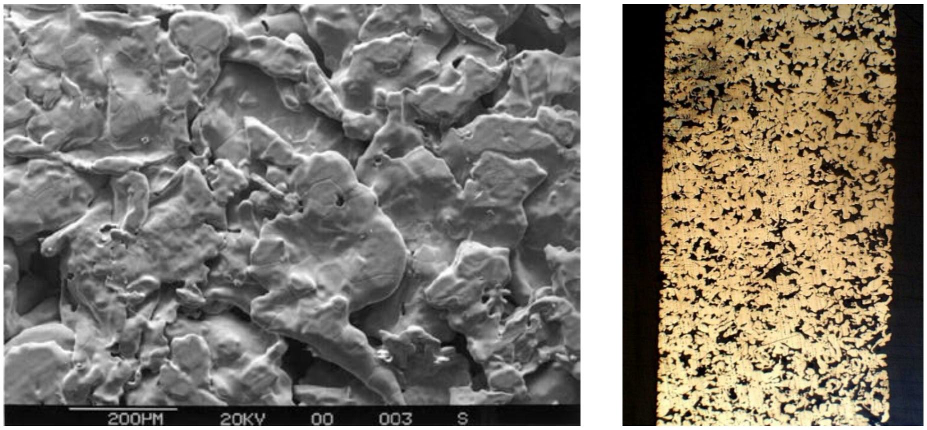

Fig. 1   Sintered Metal Powder

The low porosity results in low permeability and the manufacturing methodology limits geometry to largely plain cylindrical filters in-turn resulting in large foot prints when compared to existing fibrous technology.

Development over the last 10 years have seen the use of a fine membrane surface layer on a course structure enabling increased efficiency and improved permeability characteristics.

METAL FIBER MEDIA

Sintered Metal fiber media is a random laid (Non-woven) matrix of sintered metal fibers as shown below.

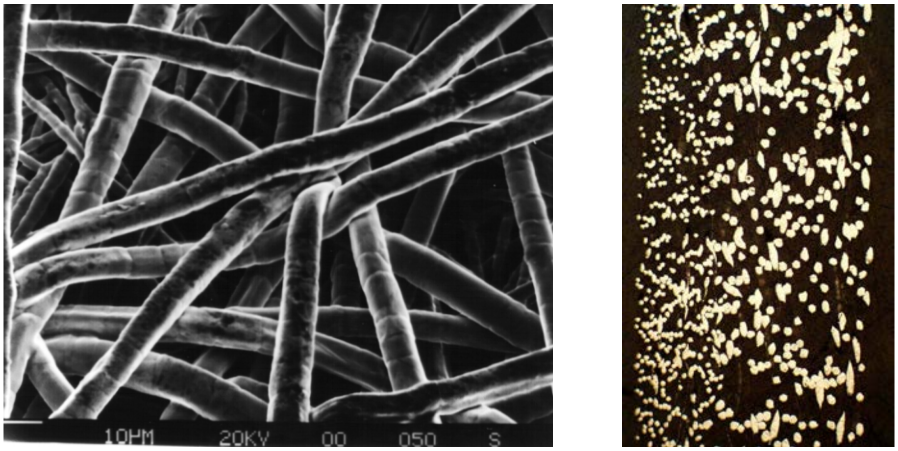

Fig. 2   Sintered Metal Fiber

The starting point for the manufacture of metal fibers is a wire of 0.5 mm diameter, which is drawn down, encased in a copper sheath, and then bundled together with many other such wires. The bundle of encased wires is further drawn down in multiple drawing steps until the correct fiber diameter is obtained (diameters can range from 1 to 30 µm). The copper sheath is leached off and the fibers are chopped into 25 mm lengths. Fibers can be manufactured in AISI 316L and AISI 304 stainless steels and a range of specialty steels. The fibers are formed into a web by either air or wet laying techniques in densities ranging from 75 to 900 g/m^2. For sintering, panels are stacked up separated by Monel mesh to prevent webs sintering to each other (sometimes 2 or 3 webs are combined together to produce a 2 or 3 layer medium), and placed in a vacuum furnace with a static load on top. The furnace is vacuumed down and heated to a temperature around 1000 ºC to form diffusion bonds between touching fibers; this produces a porous metal "paper" with the sinter bonds acting as the binder to impart strength. In order to achieve the correct filtration rating the sintered webs are pressed to a defined thickness, and tested for air permeability, thickness and weight.

Sintered Metal Fiber media possesses many of the positive attributes of the traditional microglass fiber media’s, random laid non-woven fine fibers enable high efficiency filtration at the fine submicronic particle range. High porosity and thus high permeability, and able to be pleated thereby enabling volume reduction.

However Metal Fiber offers the advantage of: thermal stability and is suitable for use at temperatures in excess of 500°C; high mechanical strength – high differential pressures without loss of integrity; unaffected mechanically by humidity and moisture, and resistant to fatigue.

PULSED JET, SELF-CLEANING METALLIC HEPA FILTRATION

Reverse flow cleaning of metal, ceramic and polymeric filters is common practice within numerous environments from cement plants to pharmaceutical and petrochemical. The principles of operation are generally well understood and documented.

In the case of metal fiber the removal and recovery of contaminant from the gas stream is based on the buildup of particulate on the surface of the filter medium. Typically an asymmetric fiber structure is utilized with a fine layer on the outer surface to maximize surface filtration.

The subsequent regeneration of the filter is achieved by the introduction of a rapid pulse of compressed air into the clean side of the filter causing a pressure shock – refer to the sequence of photographs that are shown in figure 4 that demonstrate this process. As a result the gas flow is reversed and the particulate layer dislodged from the filter. The removal of the solids layer is dependent on two mechanisms, the shock wave emitting from the sudden pressure rise and the reverse gas flow.

Fig. 4 Pulse Jet cleaning of Metal Media HEPA Filter

Moving across the photographs shown in figure 4 from left to right: (i) the metal fiber element loaded with dust; (ii) the dust is removed from the surface by the pulsed jet action; (iii) the dust is carried away; (iv) the dust begins to settle; and (v) quickly falls to the bottom of the vessel leaving a clean element. Sequence time - half a second

Ultimately the dust layer can be removed if the forces acting up it during reverse cleaning overcome the forces adhering the layer to the filter medium. The very high porosity/ low permeability of metal fiber media enables higher forces to be delivered to the cake/ media interface compared to sintered metal powder filters.

Regeneration Test Programme, proof of concept

To demonstrate the regeneration characteristics of Sintered Metal Fiber, Porvair conducted a test programme based on the supply of a Glovebox Pulse Jet Filter for MOX Pellet Grinding. The test results were subsequently used as part of the Filters Production Acceptance Test schedule. The test filter comprised seven Pleated Sinter Metal Fiber Filters housed in a pressure vessel. Individual reverse flow pulse jet nozzles were located above each filter.

Fig. 5 MOX Pellet Grinding PulseJet Filter installed in test and development Facility

TEST CONDITIONS

Air Flow	$200m^3$/hr
Filter Area	$1.6m^2$
Number of Elements	7
Initial Clean Pressure Drop	5.4mB (7.7mB @ $250m^3$/hr)
Stabilized Operating Pressure Drop	13.6mB @ $200m^3$/hr
Powder Size Range	90% ≤ 1µm (by mass)
Powder Density	Iron Oxide
Powder Feed Rate	330g/hr ($1.64g/m^3$)
Temperature	Ambient
Pulse Length	0.3 secs
Pulse Pressure	1.8Bar g

Filtration Efficiency

Initially a fractional filtration efficiency test was performed using Iron Oxide test dust. The dust was fed into the rig using a TSI Dry Powder Dispenser at a rate of 49.5 g/hr. The aerosol was detected using a Laser Aerosol Spectrometer. Particle counts were measured in the 0.09 – 3.0µm range.

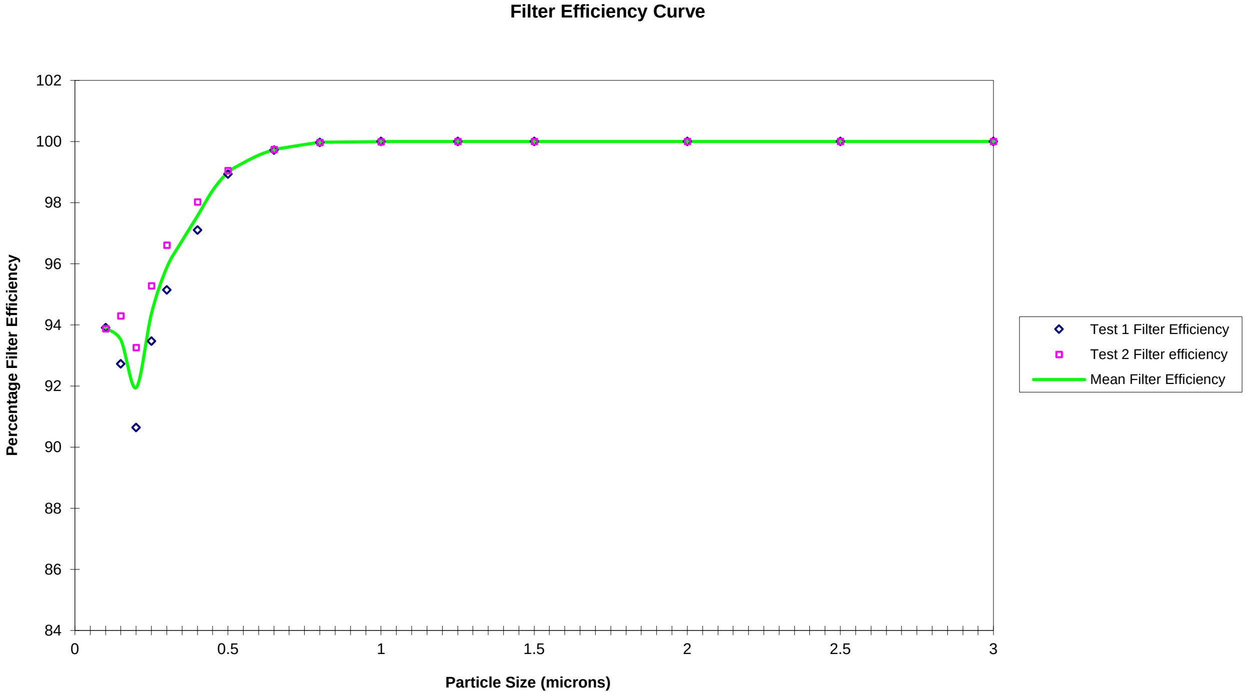

Fig. 6 Fractional Filtration Efficiency Sinterflo® Sintered Metal Fiber

PulseJet Filter Regeneration Tests

Summary of Results

Mean Clean ΔP:	6 mbar
Mean Stabilized ΔP:	13.6 mbar (averaged)
Pulse Interval:	12 seconds (cycle time 96 sec)
Typical Reservoir Decay:	0.5 bar
ΔP Recovery (per pulse):	0.5 mbar (typical)
Total Dust Loaded:	720 g
Total Run Time:	7704 s
Dust Recovered:	413 g (blowdown)
Dust from Vessel Interior:	152 g (strip down)
Total Dust Recovered:	565 g
Overall Recovery:	78.5 %

Figure 7 illustrates three traces following 0g, 180g and 360 grams of loaded simulant against time. From the residual value, the ΔP quickly tended towards a stable mean operating ΔP, as the graph suggests. The rolling nature of the 360g 'stable' operating condition trace is accountable by the pulse sequence, as expected and highlighted in initial discussions. Since the controller is manufactured for eight outputs and the unit is designed with seven valves to operate, each cycle contains a 'null' pulse. During this period, the simulant continues to load and the ΔP increases beyond the mean. The following seven pulses reduce the ΔP, in succession, to below the mean value. The graph illustrates the pulse interval, duration, recovered ΔP and the dust constant load, as detailed above.

Blowdown

Following each day of functionality testing, the unit was pulsed in a cyclic manner, as per normal operation, without any further dust loading, until a near stable operating 'clean' ΔP had been achieved.

Simulated Periodic Pulse Failure

A test to simulate periodic downtime of the pulse controller / blowback system was conducted. From the operating stable ΔP, the unit was loaded with dust without any blowback pulses. When the differential pressure reached 15 mbar the blowback system was initiated. Once the dust feeder had run out of simulant, the unit was allowed to blowdown as described above. Figure 8 shows the loading, recovery and blowdown of the unit.

It can be clearly seen from figure 8 that the ΔP across the filters was tending back toward the mean operating level, during the period the dust continued to be loaded. Furthermore, the blowdown of the unit showed that the unit is capable of reaching a residual ΔP.

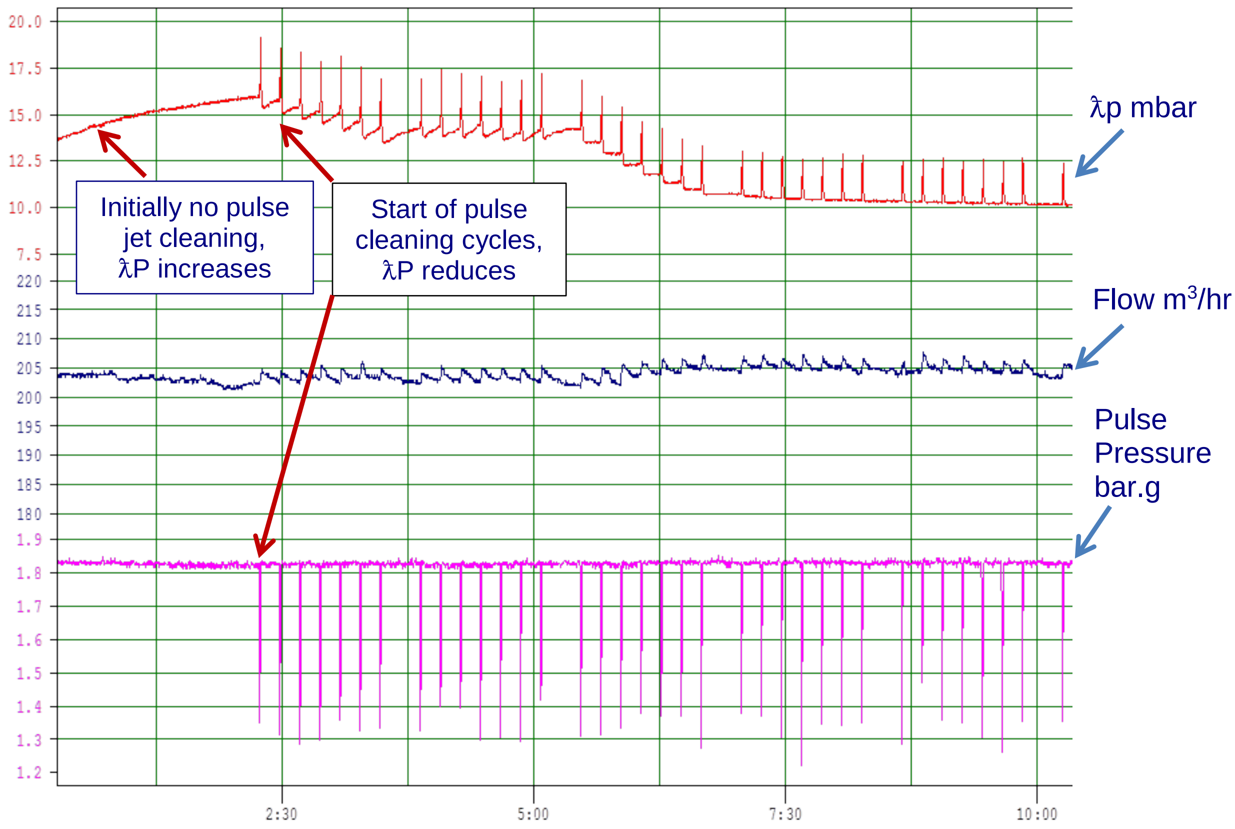

Fig. 7 Development of the stable regime (operating) ƛp showing system air flow and frequency of pulse jets at fixed time period

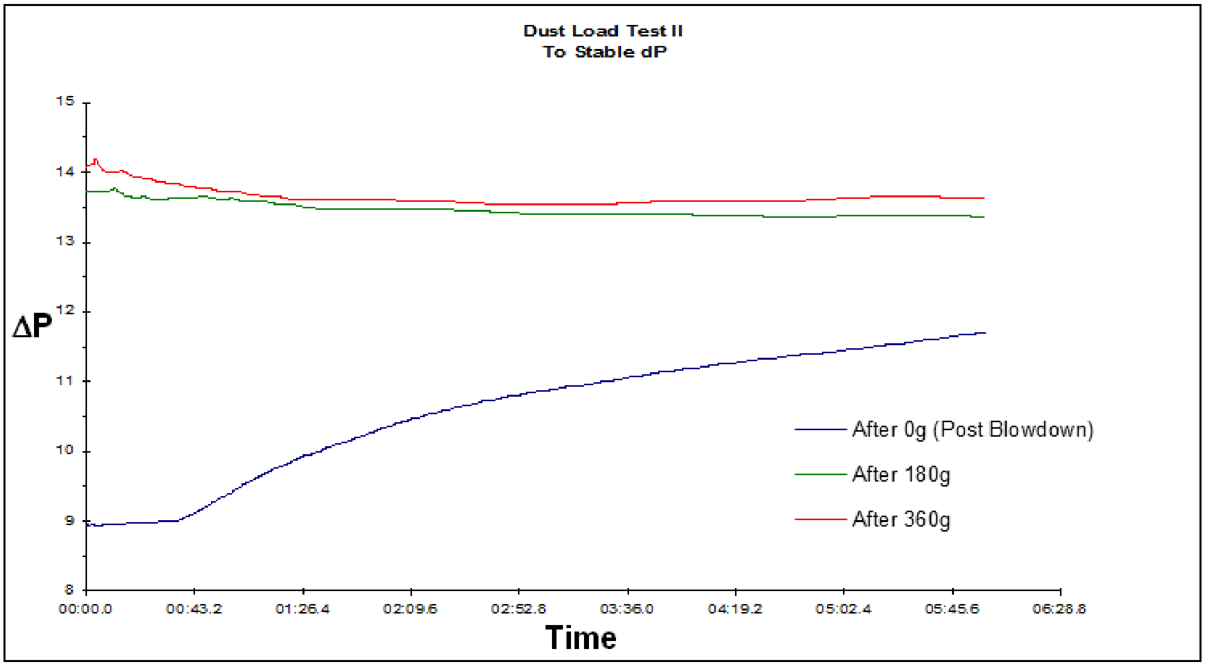

Fig. 8 Development of the stable regime (operating) ƛp after loading a clean filter with simulant and with on-going pulse jet cleaning

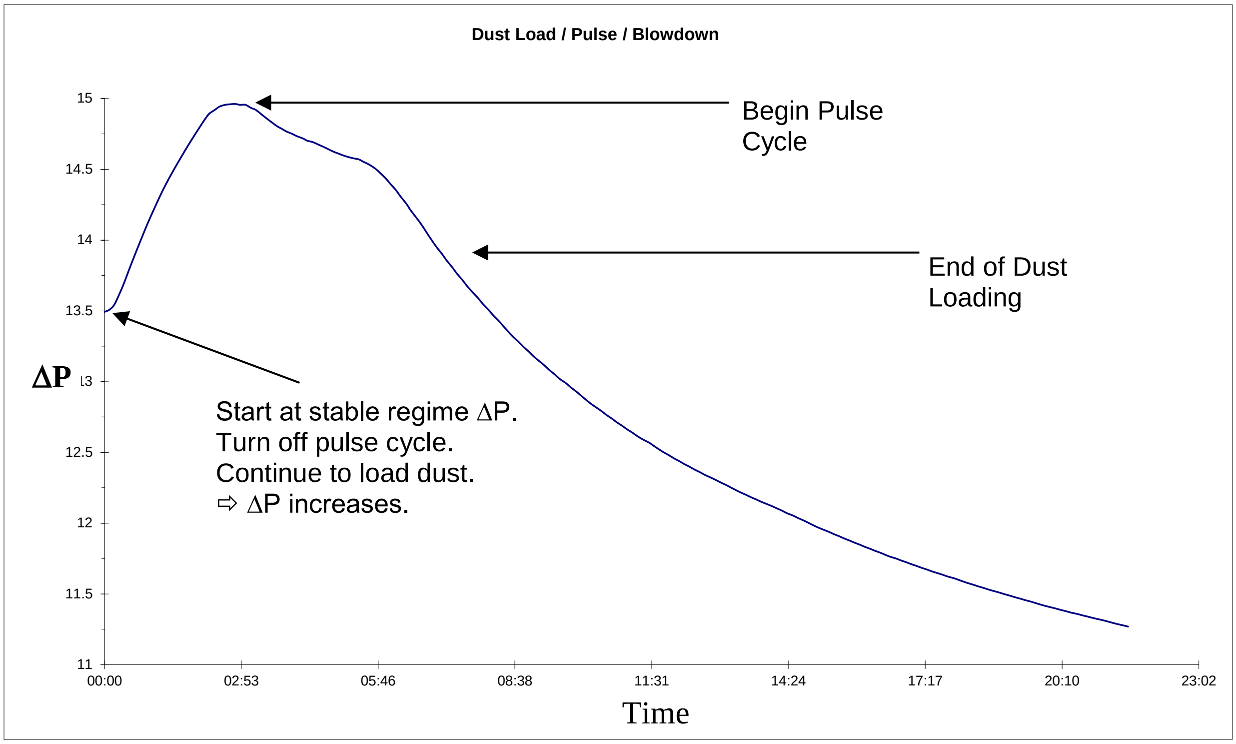

Fig. 9 Simulated Pulse Valve Failure/ Blowdown Characteristics

CONCLUSION

Traditional Microglass fiber HEPA filters provide a proven and well-regulated technology solution for many applications within today's nuclear industry. However the limitations of temperature, mechanical strength, moisture and radiological resistance may exclude the use of these filters in applications such as: nuclear decommissioning with high radiation / high volume dust loads, applications with damp particulate, fume ventilation at high temperature and long-term waste storage.

The results from tests by Porvair Filtration Group has shown both the efficacy and long term stability of Pulsed Jet self-cleaning HEPA grade metal media filters (>99.97% @ 0.3 microns). The existence of such a technology brings solutions to a number of intractable problems in the nuclear industry and beyond, thus allowing HEPA filter protection in environments where this was previously impractical. The use of HEPA grade metal media filters removes the need for scrubbers, diluters or heat exchangers downstream of the process to allow contaminant removal to take place.

The development of sintered metal fiber media enables particulate collection efficiencies to be achieved comparable with those of traditional glass fiber media with minimal pressure loss. Porvair Filtration has demonstrated the regeneration characteristics of asymmetric metal fiber media and thus their potential for such applications.