COST AND WASTE VOLUME REDUCTION IN HEPA FILTER TRAINS BY EFFECTIVE PRE-FILTRATION

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ABSTRACT

Data published elsewhere (Moore, *et el* 1992; Bergman *et al* 1997) suggests that the then costs of disposable type Glass Fibre HEPA filtration trains to the DOE was $55million per year (based on an average usage of HEPA panels of 11,748 pieces per year between 1987 and 1990) $50million of which was attributable to installation, testing, removal and disposal – although the life cycle costs are themselves based on estimates dating from 1987-1990.

The same authors suggest that by 1995 the number of HEPA panels being used had dropped to an estimated 4000 pieces per year due to the ending of the Cold War. The yearly cost to the DOE of 4000 units per year was estimated to be $29.5 million using the same parameters that suggested the previously stated $55 million for the larger quantity.

Within that cost estimate, $300 was the value given to the filter and $4,450 was given to peripheral activity per filter. Clearly, if the $4,450 component could be reduced, tremendous saving could result, in addition to a significant reduction in the legacy burden of waste volumes. This same cost is applied to both the 11,748 and 4000 usage figures.

The work up to now has focussed on the development of a low cost, long life (cleanable) direct replacement of the traditional filter train, but this paper will review an alternative strategy, that of preventing the contaminating dust from reaching and blinding the HEPA filters, and thereby removing the need to replace them.

What has become clear is that ‘low cost’ and ‘stainless HEPA’ are not compatible terms. The original Bergman *et al* work suggested that 1000 ft^3/min stainless HEPAs could be commercially available for $5000 each after development (although the $70,000 development unit may be somewhat exaggerated – the authors own company have estimated development units able to be retrofitted into strengthened standard housings would be available for perhaps $30,000). The likely true cost of such an item produced industrially may be closer to $15,000 each. That being the case, the economics for replacing glass fibre HEPAs by a metallic, cleanable alternative are unjustifiable except on ethical grounds.

By proposing the protection of the traditional Glass Fibre HEPA from it’s blinding contamination, a means is presented to reduce their life costs and reduce ultimate waste volumes.

An examination of the case for self-cleaning HEPA protection also suggests that, even when the mechanical life limit of the HEPA train is reached, the degree of contamination could be reduced

to such an extent that it’s means/classification of final disposal may be modified to further reduce cost.

Pulsed jet filtration using metallic filter media is a practical and industrially proven means by which solids can be prevented from reaching the HEPA train and returned to the operator for disposal, whilst not interrupting the process flow through the system. Field experience and data to prove the contention is available.

There are clearly benefits with regard to disposal in returning to the user the small quantities of dust that would otherwise lead to the contamination and blinding of the large volume of the filter train.

A cost benefit analysis shows that this radical solution to HEPA cost amelioration can work. Presenting a review of the technology and it’s application to other areas illustrates that where gross dust removal or recovery is necessary, or where extreme conditions make traditional HEPA technologies impractical, metallic filtration systems can (and do) also offer economic and industrially real solutions.

INTRODUCTION

For several years now, the economics of replacing traditional, disposable HEPA filters have been explored by the industry, with a view to achieving a HEPA filter which could, by some means, be reliably re-used after cleaning.

This, of course, raised a few difficult questions. The method of cleaning could itself generate a greater volume of waste than was represented by the filter element in the first place, particularly if the cleaning method used a liquid solvent, water or acid. The material from which the filter media itself was made had to be capable of withstanding the rigours of cleaning and still offer reliable and repeatable filtration performance, which would then have to be tested before re-installation. Clearly, an obvious solution to the question of a robust filter was to use a metallic medium. This solution then raised the subsequent concern that, should the particular element not recover from it’s cleaning process, and fail it’s efficiency test, it could not be volume reduced to the same degree as a traditional glassfibre chassis, either by crushing or burning.

Cost was also a significant issue. Despite the work done by several companies in the filtration industry, as well as by national and academic institutions, the conclusion drawn in the 90s by *Bergman et al* and *Moore et al*, that the post development industrial price of metallic 1000 cfm HEPA filter bodies could be around $5000 each has proved somewhat optimistic, a real market price probably being closer to $15,000 each in the quantities identified by those authors.

In addition, the permeability of metallic media capable of providing HEPA efficiency has proved disappointingly poor with the consequence that systems would have to be bigger, or pressure drops greater. Either case leads to increase costs, either from initial capital expenditure or from operating costs.

Another aspect of the issue is the ‘non-standard’ use of process HEPA filters. High performance, metallic HEPAs clearly have a place in the nuclear industry, but their application is necessarily limited.

Traditional HEPA filter systems have limitations that often prevent them from solving many of the 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 or resistance to moisture are issues. Several of these duties have be solved by the use of metallic filter media; including the long term storage of transuranic waste at the WIPP site; the long term storage of spent and damaged fuel assemblies; glove box ventilation; tank venting; the venting of fumes at elevated temperature from incinerators, vitrification processes and conversion or sintering furnaces; as well as downstream of iodine absorbers in gas cooled reactors in the UK.

Background

The HEPA (High Efficiency Particulate Air Filter) represents 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 utilised for the ventilation air of control rooms. During the 1950’s and 60’s considerable improvements were made in filter papers, improving both filtration efficiency and pressure drop. These improvements focused initially on esparto grass paper followed by cellulose asbestos and glass fibre, the latter providing one of the primary materials for today’s HEPA technology.

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

Glass fibre media provides the base technology for HEPA filters within today’s Nuclear Industry. Randomly laid microfine glass fibres, typically down to 0.3um or less, form the core structure of the media. Strength is given to the fibres by using a resin binder and/ or laminating to a backing scrim. The glass fibre media is then typically sandwiched between up and downstream open spunbonded fibre.

Within the US Nuclear Industry the requirement for Glass fibre 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 fibre HEPA filter is a well proven technology for the Nuclear Air Cleaning environment. Microfine glass fibres result in a highly permeable filter medium, 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.

HEPA Protection

The premise proposed here is that the best economically and environmentally responsible method of reducing the use and therefore cost of HEPA filters is not the development of cleanable, metallic HEPAs.

Not only is this method provably expensive in both capital and running cost terms, but also may not reduce the final disposed volumes anyway, as the HEPA reliability of the filter after surviving the cleaning process is not proved. In addition no account has been taken of the increased number of filters required to meet the existing pressure loss specification, or alternatively the increased energy costs to pump the air through the less permeable metal elements.

The approach suggested here is that the accepted, understood and reliable technology for HEPA protection of the environment (the use of traditional glassfibre bodies), is far better left in place, but that these acknowledged solutions to the problem of HEPA filtration should be separated from the debris which eventually causes the filter body to need to be replaced.

How may a HEPA panel or train be protected? Clearly a passive filter body in front of the HEPA panel would prevent significant quantities of dust reaching the HEPA, but the disposal problem is simply brought upstream, so this is not an acceptable solution.

What is an acceptable solution is the use of innovative technology which couples the use of long life metallic filter media with an effective, on-line cleaning method which not only allows the pre-filter to be cleaned without interrupting the process flow, but adds the absolute minimum of additional gas in the cleaning process. Properly engineered, such a system can return to the user the few grammes of dust, which the user can then dispose of separately, rather than have it enclosed in the much larger matrix of the glassfibre HEPA filter medium.

Metallic Filter Media

Metallic media offers obvious advantages in terms of mechanical strength, temperature resistance, wet strength and chemical resistance.

In addition, metallic media offer the facility of being cleanable by a percussive shockwave or reverse flow of gas through them which, to some degree, will dislodge the previously collected solids. The finer the thickness of the filter medium section, the more likely the filter medium is to give up it's solids. The greater the thickness, the more likely that the medium will retain it's solids within the depth of the medium, leading to permanent blinding.

Three main types of industrially common metal media are typically used, Sintered Metal Powder, Sintered Metal Fibre and Sintered Woven Wire Mesh. In addition to these, composite structures of mesh/ fibre and powder/ mesh are also available. Sintered Woven mesh is generally considered to filtration applications >10um and not generally suitable for HEPA protection.

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 1-100um. The powder is laid as a flat sheet or loaded to a mould and pressed prior to sintering. The resultant porous media has a 30-50% porosity and is very mechanically robust.

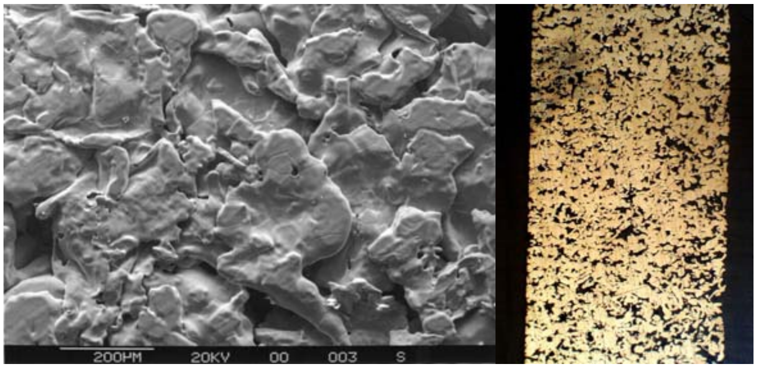

Fig. 1. Sintered metal powder

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.

Sintered Metal Fibre

Sintered metal fibre media is a random laid (Non woven) matrix of sintered metal fibres as shown below.

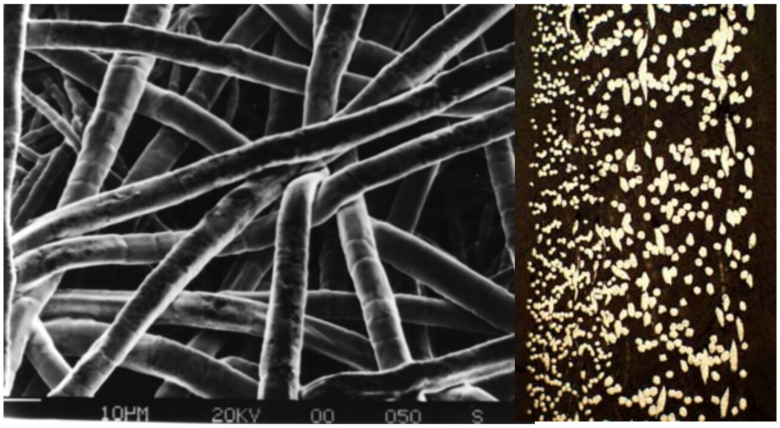

Fig. 2. Sintered metal fibre

The starting point for the manufacture of metal fibres 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 fibre diameter is obtained (diameters can range from 1 to 30 µm). The copper sheath is leached off and the fibres are chopped into 25 mm lengths. Fibres can be manufactured in AISI 316L and AISI 304 stainless steels and a range of speciality steels. The fibres 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 fibres; 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 Fibre media possesses many of the positive attributes of the traditional microglass fibre media including random laid non-woven fine fibres enabling high efficiency filtration at the fine submicronic particle range. This, coupled with high porosity and thus high permeability and it’s ability to be pleated, make possible the size reduction of the whole system, compared with alternative materials.

Sintered Metal Fibre, with it’s robust thermal stability, chemical and radiation resistance, suitability for use at temperatures in excess of 500 c, high mechanical strength, low pressure loss and ability to be pleated make it possible to use the media in special process HEPA applications. One example may be cited in particular, that of the TruVent HEPA filter breather which has been developed for waste packages destined for the WIPP site, as it has been so thoroughly tested and the performance of the filter is now well understood, although several other diverse applications are mentioned elsewhere in this paper.

HEPA Pre-Filtration, (HEPA Life Extension)

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

In the case of Metal Fibre the removal and recovery of contaminant from the gas stream is based on the build up of particulate on the surface of the filter medium. Typically an asymmetric fibre structure is utilised with a fine layer on the outer surface to maximise 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. 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. 3. Moving across the photograph from left to right: the metal fibre element loaded with dust; the dust is removed from the surface by the pulsed jet action; the dust is carried away; the dust begins to settle; and quickly falls to the bottom of the vessel leaving a clean element. Sequence time – less than half a second. The cleaning pulse is made whilst process flow continues.

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/permeability of Metal Fibre media enables higher forces to be delivered to the cake/ media interface than compared to Sintered Metal Powder filters the thick section and impermeability of which will tend to absorb the energy of the pressure front which carries the motive force to remove the collected solids.

The installation of pulsed jet filter systems upstream of HEPA banks will, to an efficiency of better than 99.9% @ 0.5 micron (and better than 94% @ 0.3 microns) depending on the application, prevent virtually all solids in this range and higher from reaching the HEPA banks. HEPA filter systems are typically tested by DOP/ONDINA with a 0.2/0.3 micron range monodispersal, because it is a given in gas filtration that across the range of mechanisms which give rise to the capture of particles, i.e. direct interception, inertial impaction and Brownian motion, the size range of least efficiency is always in the 0.15/0.3 micron size range. That being the case, a test which determines an efficiency at this size range tells the operator that at all other size ranges the efficiency will be higher.

However, this does not reflect a real world situation. A single 5 micron particle will have a volume (and therefore a mass for the same material) 4630 times the volume of a 0.3 micron particle, and 37,000 times greater than a 0.15 micron particle. HEPA filter banks are not challenged by 0.15 to 0.3 micron monodispersals, but by real world particle size spectra. Although it can be argued that efficiency at the very fine end may be more important in terms of human protection (that may be argued elsewhere, it is outside the frame of reference of this paper), there is no question that mass carry over is a particle size issue, and central to the proposition posited herein. The use of HEPA filtration may provide the possibility of reducing the mass of contamination in a HEPA bank, and therefore it’s classification when it reaches the end of it’s mechanical integrity, possibly still unblinded.

Regeneration Test Programme

There are several questions which must be examined if the concept of protecting HEPA banks with pulsed jet systems using Sintered Metal Fibre media is to be taken seriously. They include the reliability of the cleaning system; the predictability of the operating pressure loss over the long term, (maybe many years); and the recovery of the system from a fault condition.

To this end, work has been done to examine each of these issues.

To demonstrate the regeneration characteristics of Sintered Metal Fibre, test work was conducted, based on the supply of a Pulsed Jet Filter delivered to a European MOX producer to keep clean the glovebox in which final pellet grinding was conducted.

This may not be entirely representative of the challenge that a passive HEPA would typically experience, but the work does represent an extreme challenge to the concept of Pulsed Jet Pre-Filtration of HEPA banks.

The test results were subsequently used as part of the Filters Production Acceptance Test schedule. The test filter comprised 7 off Pleated Sinter Metal Fibre Filters housed in pressure vessel. Individual reverse flow nozzles were located above each filter.

Fig. 4. MOX pellet grinding pulsed jet filter Installed in MFX test and development Facility

Test Conditions:

Air Flow	200m3/hr
Filter Area	1.6m2
Number of Elements	7
Initial Clean Pressure Drop	5.4mB (7.7mB @ 250m3/hr)
Stabilised Operating Pressure Drop	13.6mB @ 200m3/hr
Powder Size Range	90% ≤ 1μm (by mass)
Powder Density	Iron Oxide
Powder Feed Rate	330g/hr (1.64g/m3)
Temperature	Ambient
Pulse Length	0.3 secs
Pulse Pressure	1.8Bar g

Filtration Efficiency

Initially a fractional filtration efficiency test was performed using the 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 – 3.00um range.

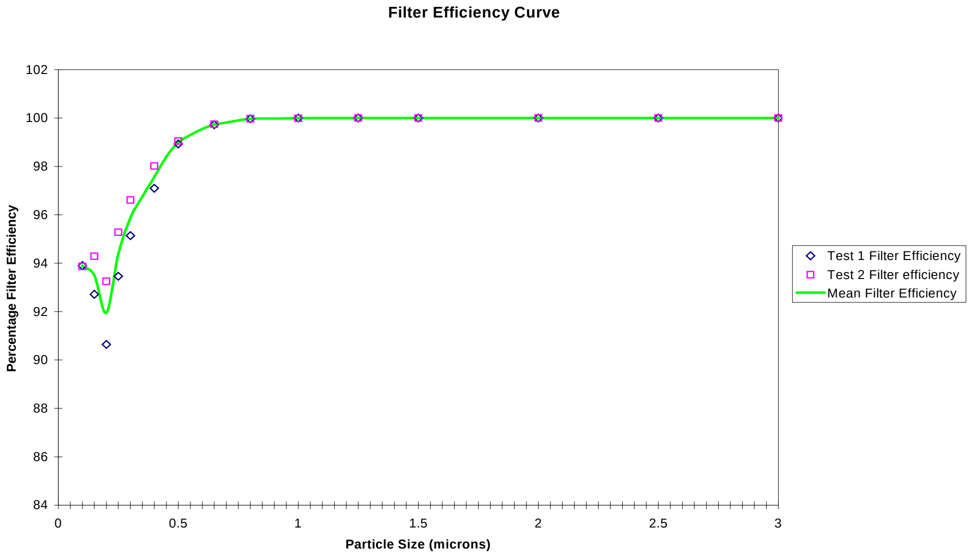

Fig. 5. Fractional filtration efficiency Sinterflo sintered metal fibre

Pulsed Jet Filter Regeneration Tests

Summary of Results

Mean Clean ΔP: 6 mbar
Mean Stabilised 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

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 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.

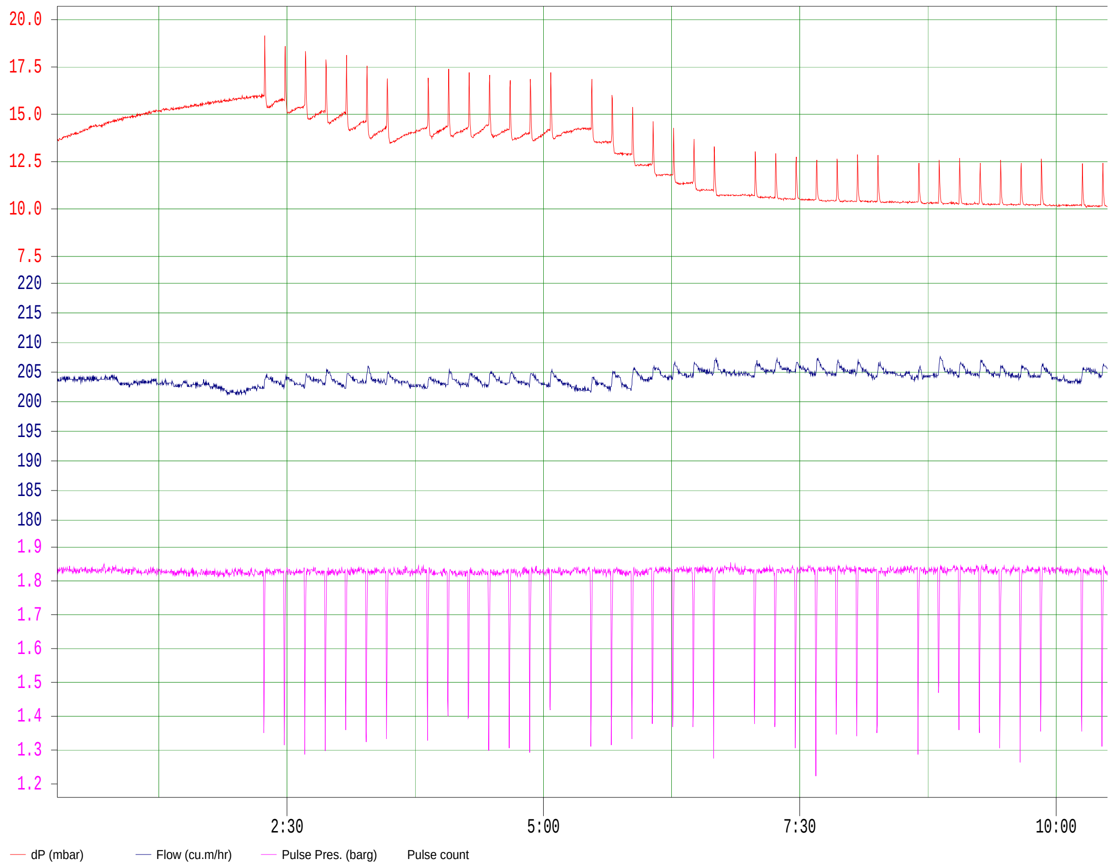

Fig. 6. Flow pressure loss characteristics/reservoir pressure

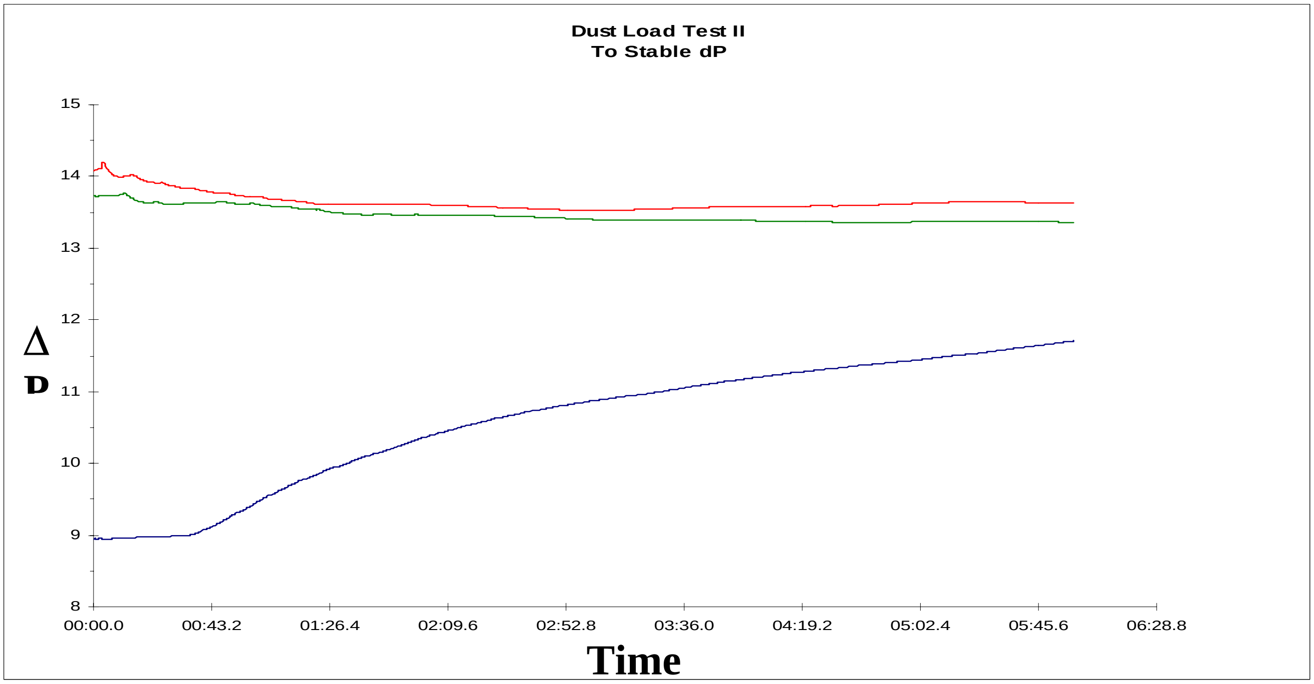

Fig. 7. Flow Δp for 0g, 180g and 360 grams of loaded simulant against time

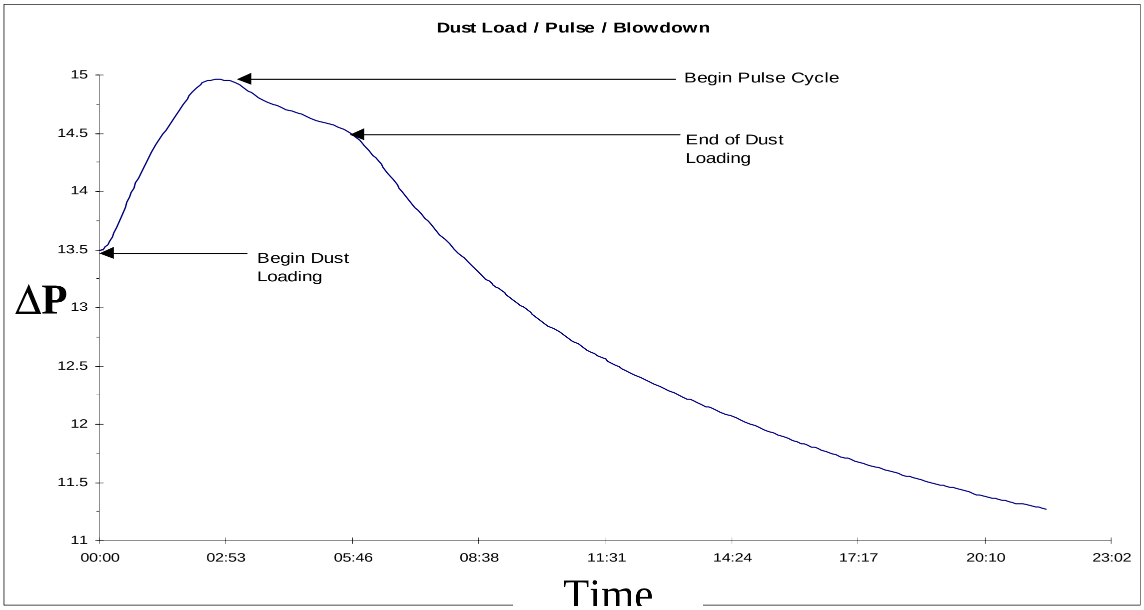

Fig. 8. Simulated pulse valve failure/blowdown characteristics.

CONCLUSIONS

It has been proven in industrially real applications that Pulsed Jet Filters operate across a range of duties in the long term, and that when blinded by a fault condition may be recovered on-line, by the normal use of the cleaning system. Moreover, the use of such systems permits the separation of the bulk of solids from a gas stream, and the recovery of the solids for re-use or disposal.

This facility may be applied to the protection of the HEPA banks, allowing the HEPA filters to perform their real function, the protection of the environment. This could, in turn, prevent the disposal of large volumes of HEPA filter elements, in favour of the tiny volumes of contaminating solids which would otherwise blind them, and which may be recovered from the system and disposed of separately.

Additional, preventing the solids from reaching the HEPAs may allow them to be re-classified and be disposed of more cheaply when the end of their mechanical lives are reached.

Material (as opposed to technological) developments of the HEPAs themselves, to extend their mechanical lives would also reduce both cost and legacy burden, if the concept of non-blinding was adopted.

If the original work conducted by *Bergman et al* is accurate in it’s estimation of peripheral costs, and if their consequent estimation of a yearly cost of c$29.5million, based on the changeout of approximately 4000 filters coupled with a saving of $16.6 million by the use of re-usable passive HEPAs is reliable, then those same values and savings may be associated with this alternative solution to the question.

However, it is also clear that the $16.6million saving was based on a $5000 ‘cleanable’ HEPA. In that case, and if the true industrial price of 1000 cfm metallic HEPA is likely to be closer to $15,000, the original economic justification for the development of cleanable HEPAs is undermined. A $16.6 million saving may actually be a $22 million cost.

At the same time, the pre-filtration of HEPA banks to prevent their premature replacement is a proven industrial reality and presents a more '‘real world'’ solution to the problem HEPA filter waste and cost minimisation.

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