Investigation into the Effects of Cyclic Particle Loading onto Filter Media

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Abstract

Virtually all industrial sectors employ air filtration as part of their processes. Unlike liquid based processes where the separation of solids from liquids forms a value adding step, in dry processes the capture of particulate material is usually not a value adding element of plant – but rather a requirement for air quality or process stability. The different roles of particle capture for wet and dry systems leads to a situation whereby models and information predicting wet filtration performance and capability are easily accessible, whilst comparable information for dry filtration (outside of the automotive and pharmaceutical sectors) is relatively poorly provisioned [9].

This paper reviews the ongoing investigative work undertaken on air filter media at The Wolfson Centre for Bulk Solids Handling Technology, UK. Aspects for filter life cycle are considered and loading phenomena are discussed.

Introduction

The primary or secondary capture of airborne particulate matter in industry is generally achieved through the use of filter elements that are enclosed within bag houses. Depending upon the nature of the particles to be captured and process operating conditions, different methods for distrainment can be applied. These can range from relatively low tech mechanically agitated frames to which filter bags are attached, through to reverse purges and more sophisticated reverse jet filter arrangements (where the filter elements are fully constrained during cleaning operations).

For either generic type of filtration operation a common plant objective is to use systems that are optimised for particle capture, energy efficiency, extended life cycle and particle release during cleaning.

Mechanically agitated filters typically are non-pleated needle felt and capture particles on the surfaces of the bag media. Such systems are operated off-line and have a longer cleaning function duration which allows good detachment efficiency for particles (these particles having only been captured during the preceding batch transfer of product within the process).

Gas purge cleaning is also undertaken off-line (with the baghouse isolated), but would normally be associated with a longer duration period of operation before cleaning. The longer run time prior to cleaning usually dictates that a higher areal density will accrue within and on the surface of the filter media. The large volume counter directional gas flow has a higher potential to dislodge particles from within the filter form (which is more likely to be pleated and synthetic wet lay form).

Reverse gas pulse filters are commonly found across a wide range of industries and are effective in many applications. The diversity of applications and end user requirements has led to an array of options relating to detail design, operation and construction of such systems. In contrast to off-line cleaning systems, reverse gas pulse cleaning typically has a very short duration (~0.1 seconds) – the initial phase of which is absorbed in equilibrating gas pressure across the filter face before any cleaning function can occur. The brevity of the cleaning function dictates that as little as 10% of the

material displaced by cleaning actually deposits into the filter housing – the remainder being brought back onto the filter media as the decaying pulse pressure is replaced by the ambient (counter directional) gas flow within the filter housing [1].

Overview of particle capture characteristics

Many chemical and process engineers are familiar with the operation of particle capture in wet based processes where disengagement from the fluid takes place against the surface of the media. Particle capture occurs in progressive and distinctly different stages for gas solids separation. Excepting the shaker type media (where particle capture is predominantly on the surface), gas purge and gas pulse media undergo a transitional particle capture which can be used to optimise the capture capacity and hence service duration before a cleaning cycle is required.

Three phases of operation can progressively develop (Fig 1); in-depth, surface and blocking. Assuming a start point using a media that is completely devoid of captured particles, the initial lodgement of particles will occur into the accessible voids formed within the filter media. This generates an initial progressive increase in pressure drop through the media as particles are captured in-depth. As the internal voids become saturated, particles begin to accumulate onto the outer surface of the filter – creating an increasingly higher pressure drop as the surface bed deposition thickens.
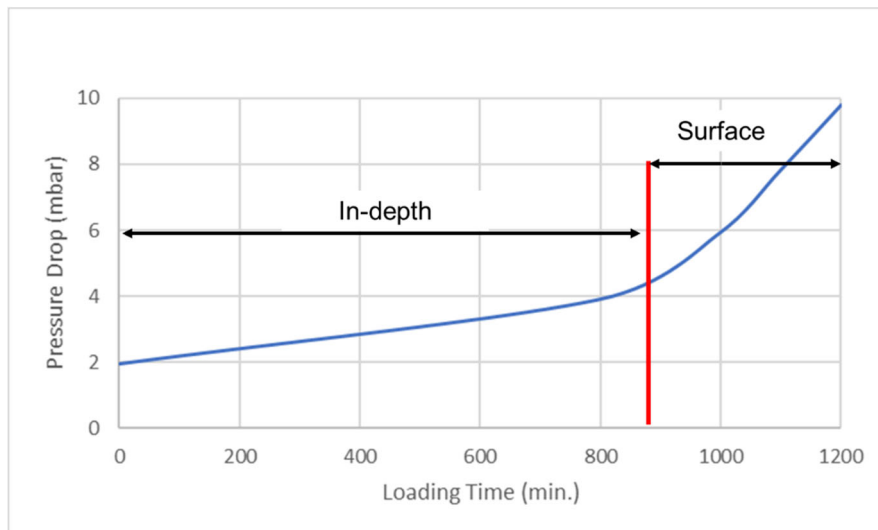
Fig 1   Graph showing typical change in pressure gradient at the transition from in-depth to surface capture [2]

For most gas / solid capture systems, the peak pressure drop at which cleaning is triggered would normally occur at some value into the surface deposition regime. Occasionally specialist process requirements dictate that the duration between cleaning cycles must be optimised. This type of requirement is unusual, but under such circumstances the particle capture regime is continued as close to the blocking condition as possible. Fig 2 shows the progression from in-depth to surface to a final blocking condition. This approach would be applied to a filter system requiring off-line cleaning within a specialist production process.

It is clear that the selection of filter media and its optimal operation are key to the life cycle costs for a given filtration system. If an inappropriate selection of media is made or the cleaning system design/control is not optimal, the ongoing costs associated with compressed air consumption and frequency of cleaning can become excessive.
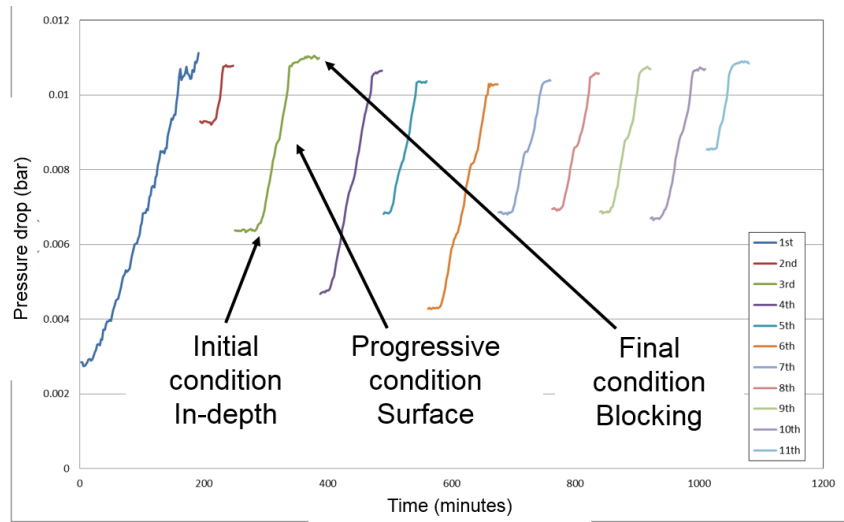
Fig 2   Pressure record showing progression to blocking

The ability of a given filter system to capture particles is clearly of primary importance, but equally important is the ability of the filter media to release captured particles during the cleaning cycle. A more important way to view the latter statement is that when in operation the filter should support a minimal increase in the quantity of irretrievably embedded material (once the filter has 'bedded in' to its stable working condition). Fig 3 presents an example of the multiple loading and cleaning ΔP characteristics for a sample of synthetic wet laid media.
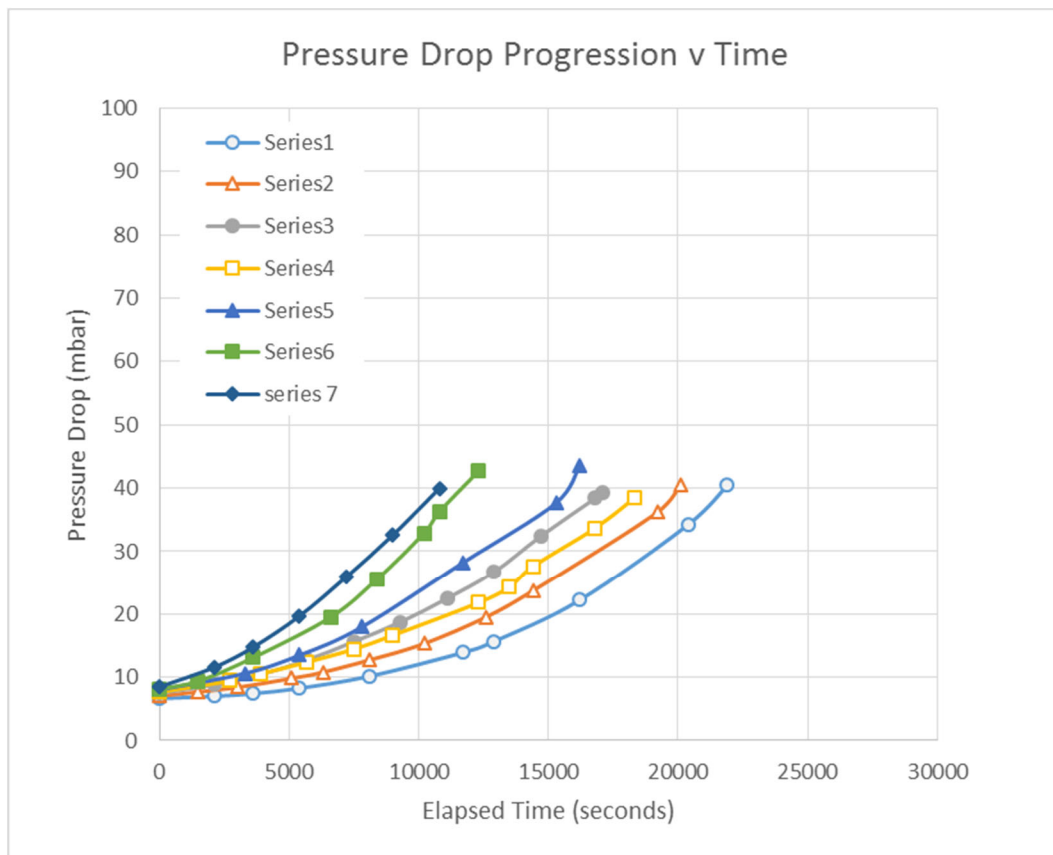

Fig 3   The ΔP development characteristic for a synthetic media used in conjunction with carbon black

Notable in Fig 3 is the regressive time taken to reach the peak ΔP. This type of behaviour is typical for a new filter being brought into service and indicates an increasing population of particles

irretrievable lodged within the structure of the filter media. The speed with which ΔP is reached for a given media type is mainly a function of the face velocity of the particles as they interact with the media, the size distribution of the particles and concentration of particles. Referring again to Fig 3, tracks 1 to 5 show a typical regression over successive tests. These tests were undertaken with a stable powder feed rate of ~0.0007 g/m). Increasing the feedrate to ~0.0009 g/m, resulted in tracks 6&7 and a decrease in the time taken to reach a user defined peak ΔP. A key consideration for this data set is that it has been obtained using a laboratory test rig and represents results using a 60mm diameter flat sample of filter media. For a full size filter unit a greater number of 'clean to dirty' cycles would be necessary for the filters to reach a full 'conditioned' state (i.e. most filters rely on a baseline loading of particulate material as part of their function).

The trends in Fig 3 were obtained using a wet lay fibre filter media (Fig 4, below). Examining the form of the media, the non-uniform nature of the lay is apparent.
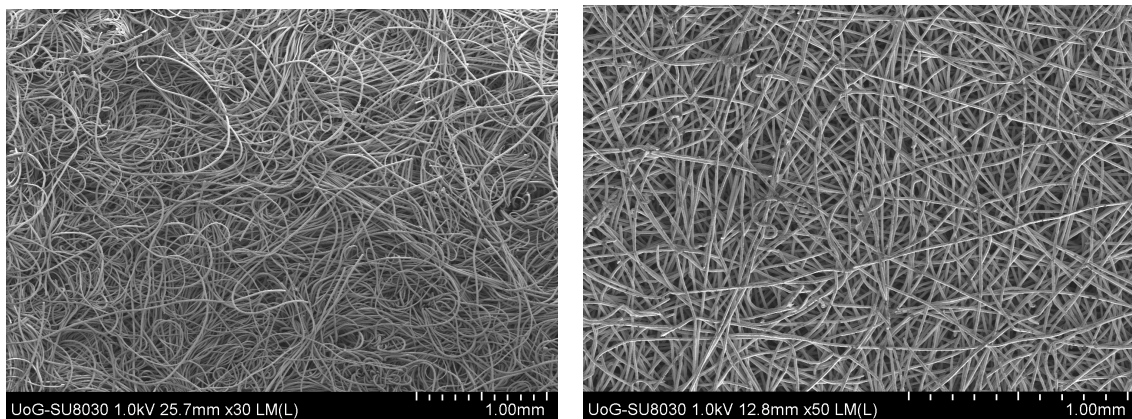
Fig 4   Polyester fibre (left) & stainless steel (right)

Clearly particle capture is unlikely to be homogenous in cross-section or depth in the early stages of filter loading due to the infinitely varying proportions and volumes of the passageways formed between the fibres. At a microscopic level of inspection, the most convoluted or constrained pathways will invariably give rise to initial and progressive particle capture, whilst more 'open' pathways will serve to transport particles deeper into the media and a greater number of 'tributary' channels. Choking of initial preferential channels will increase the functional contribution of progressively constricted tributaries – thus the macro scale pressure drop through the media builds as the volume of particles occupying accessible voidage increases. Variables such as particle form, size distribution and local face velocity all influence the depth and strength of penetration into the media. The work of many researchers [3,4,5] consider filter pressure drop in the context of single or multiple filters, but clearly the values reported in this way can only be aggregate values for entire units that cannot capture or express local pressure development. The reality for many filter installations is likely to be that the distribution of particle mass and face velocity development varies over the face of a filter in response to proximity to the inlet pipe, adjacent filters or the spatial layout of the filter housing. Local face velocities acting against the filter will be a function of local particle population present in/on the media. If the filter begins to load with material unevenly, then local face velocities can begin to increase over areas that have not developed such a high pressure drop. Where this situation occurs, the rate at which pressure drop develops can rise significantly. Fig 5 shows this effect using a single candle test rig at The Wolfson Centre with identical solids loading in the air flow. Increasing face velocities not only decrease the time to reach a given pressure drop, but have the potential to embed particles more forcefully into the media – making the need for efficient particle dislodgement all the more critical (and usually more difficult to achieve).
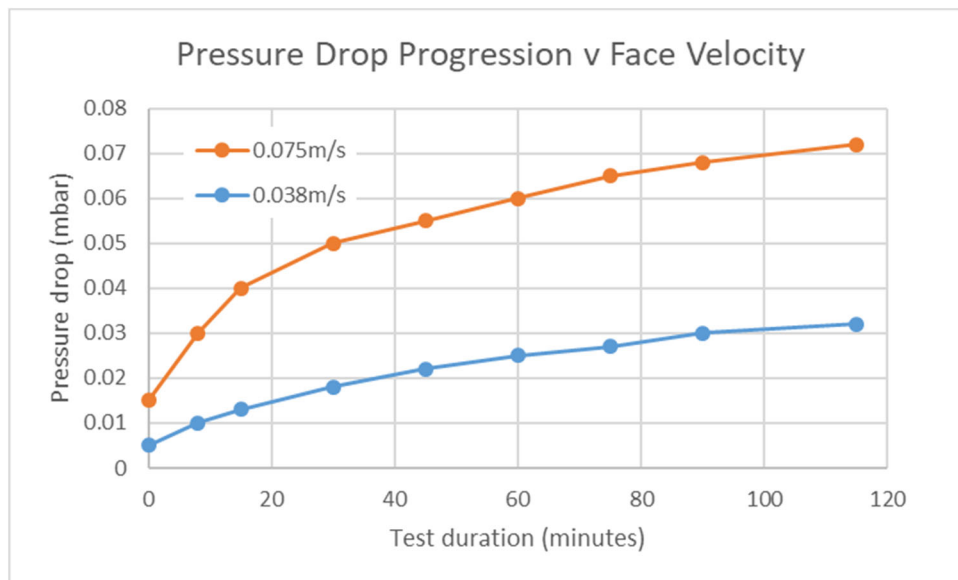
Fig 5   Graph showing a correlation between increased face velocity and pressure drop across a single filter candle

Although particle properties and operating conditions contribute to the development of pressure drop, an additional effect that can develop is related to dendrite formation on the face of the filter. Several previous researchers [6, 7] have identified this effect which is caused by the attraction supporting the accumulation of particles into vertical structures.
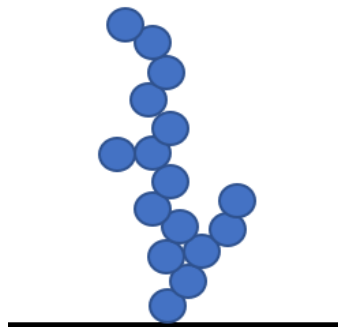

Fig 6   Schematic of a dendrite form extending away from a filter face

The presence of dendrite forms can make a progressive contribution to the pressure drop that develops across the face of the filter. Although this effect is very difficult to image capture whilst the dendrites are in situ, their impact can be readily detected by examining the pressure drop characteristics for filter media/particle properties. Examination of Fig 7 shows evidence of dendrite formation for carbon black against a metal filter element. It can be seen that pressure drop development progresses from the 'clean condition' up to the fourth test – following which the test rig was left inactive for a period of one hour (note that the time axis is cumulative running time). It can be seen that the 'clean' pressure drop recovered to a notable extent over this period. This effect has been recorded by previous researchers and is generally attributed to the effect of dendrite collapse – which would support a suspicion that electrostatics may contribute into the formation of dendrites (hence charge decay over time encourages the collapse of these structures – leading to pressure drop recovery) [7].
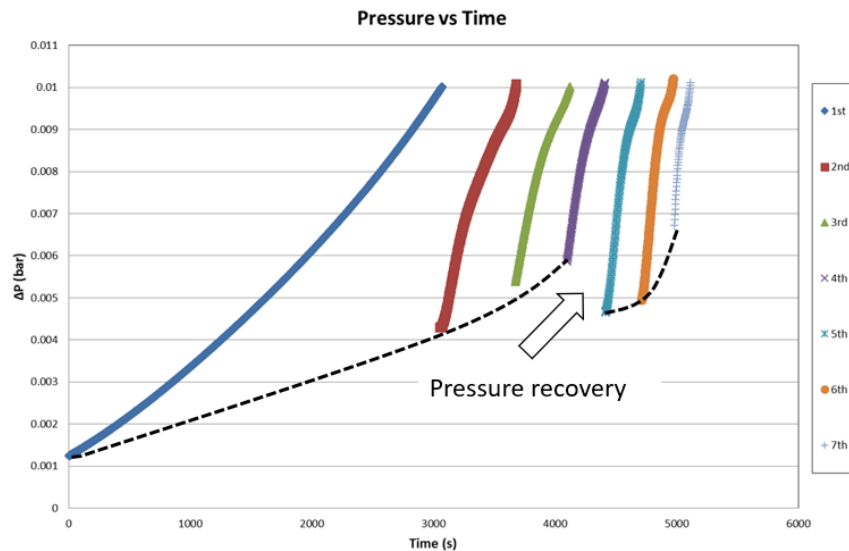
Fig 7   Graph showing pressure recovery between test cycles

Clearly controlling face velocities is an extremely important factor in specifying a filter that is intended to provide efficient operation (capture, release and energy efficiency). A common approach to control face velocities is to increase area of a filter by using pleats. Using this construction method considerable surface area can be created. Correspondingly, filter lengths can also be increased to provide large filter areas – which also supports a maximisation of filter area within a finite footprint for a filter housing in an industrial installation. Such pleated cartridges can usually be supplied in either parallel of tapered formats. Currently the understanding of the effect of pleat geometry on particle capture and release is not well understood and has received scant research. However, it is logical that somewhere between 179° and 1° included angles for a pleat an optimal geometry must exist. This contention is supported by previous work that, although not directly addressing pleat geometry, considers effects that have implications for the presence of an optimal pleat configuration (Fig 8).
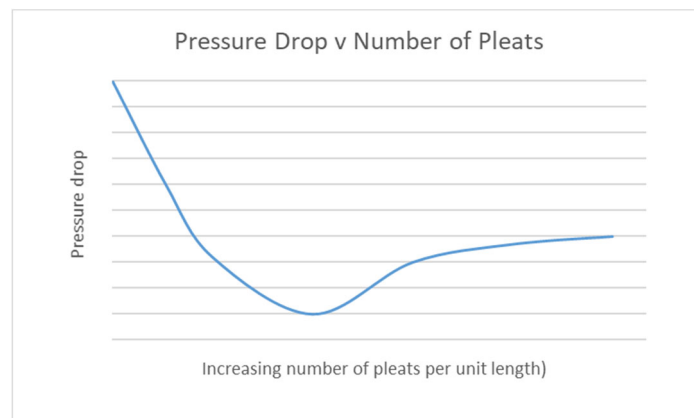

Fig 8   Graph showing pressure drop changes in response to increasing numbers of pleats [8]

Taking into account the extremes of possible pleat geometries it is implausible that the particle capture and release characteristics can be consistent for all pleat forms - particularly so when the effects of gas pulse pressure variations down a filter are taken into account during cleaning. This is an area of research that is very much in need of investigation.

Conclusions

The science and technology of particulate filtration systems is still a developing aspect of the application of best practice in bulk solids handling with industry. Whilst many systems operate as designed and do not give undue problems, there is also a large number of systems that underperform and require regular intervention. It can be argued that the misguided perception that filtration units do not directly drive efficiency or profit margins is largely behind the 'value engineering' exercises that result in the installation of marginal systems. There are many aspects of filter specification that are not well understood (at a technical level) by those responsible for writing or reviewing specifications – which can carry significant risk for projects. This brief paper has highlighted some of the major considerations and hopefully shed some light on the subject for engineers.

References:

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