Determination of Relevant Characteristics for Cartridge Filters

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Introduction

Cartridge filters are widely used in liquid-solid separation processes. To select a proper filter system for the requirements of a given application, a knowledge of filter efficiency and dirt capacity is required.

The filter manufacturer needs to provide data which are based on test procedures simulating real parameters on a laboratory scale.

There does not exist at present a standard for liquid filter testing (with the exception of the Multipass Test to ISO4572 for hydraulic filters). Users have to work with data based on different test procedures.

This paper will discuss principles of filter testing, efficiency and dirt capacity results as a function of test parameters, and data interpretion to provide a guideline for the end user.

History

The range of methods available for determining cartridge filter characteristics can be better understood by considering the parallel development of filter types and filter test procedures. This observation particularly applies to the measurement of the efficiency, or particulate removal rating.

Early cartridge filters were constructed from a square weave mesh, typically stainless steel. In such meshes, every hole or pore is nominally the same size, and a measurement of the size of one pore can be used to establish some measure of the particulate removal rating of the filter media. This measurement can be accomplished either by evaluation of wire counts and thicknesses, or by direct observation using microscopy. As filters developed, it was established that finer filters, with increased strength, could be manufactured using different weaves for the mesh, such as a dutch twill weave. (Fig 1). The direct observation of pore size, and calculation of hole size from wire counts and thicknesses become difficult, if not impossible, with this type of mesh. Consequently, a number of methods of establishing the particle removal rating were developed. These methods were still based on the premise that, since all pores were nominally the same size and shape, the determination of the characteristics of one pore could be used to predict the performance of the whole filter.

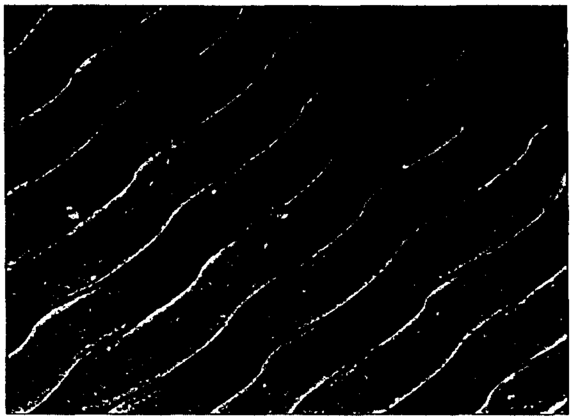


FIGURE 1:
Woven Wire Mesh (Dutch Twill)

In addition, it was recognised that indirect methods of filter evaluation suffered certain drawbacks, and that direct measurement of filter performance gave considerable benefits.

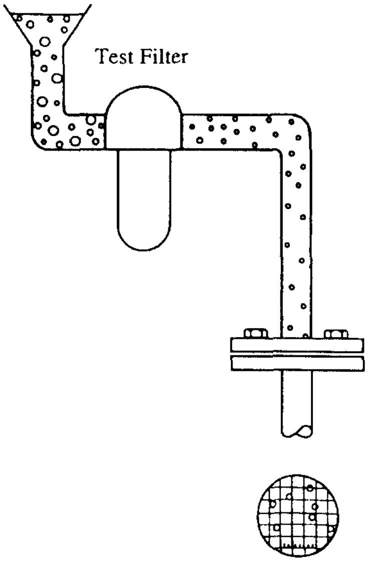


FIGURE 2:
Glass Bead Test

This led to the development of the glass bead test, such as described in MIL-F-8815 (Ref 1), which consists of passing a distribution of glass beads in suspension through a test filter under defined test conditions, then passing the filtered suspension through an analysis membrane. The analysis membrane was then searched, and the largest glass bead identified and measured. This measurement was taken as the absolute rating of the filter. (Fig 2). So, the absolute rating of a filter was defined as the largest hard spherical particle which would just pass through the filter.

An alternative indirect measurement that was used has been loosely called the bubble point test, such as described in ARP901 (Ref 2). This is based on the observation that, if a circular hole in a flat plate is fully wetted in liquid, the minimum bubble radius that the hole will support is the radius of the hole. The differential pressure across the bubble under these conditions is controlled by the surface tension, so that

$$\partial P = \frac{2\sigma}{r}$$

where ∂P = differential pressure
σ = surface tension
r = radius of bubble

Since the minimum bubble radius corresponds to the maximum differential pressure before bubbles are released from the hole, the measurement of differential pressure can be used to establish a size for the hole.
ARP901 extends the method to triangular holes in flat plates, but it must be recognised that the measured differential pressure is also dependant on the shape of the hole.

$$\partial P = \frac{k\sigma}{r}$$

σ = surface tension
r = pore size
k = constant (shape dependent)

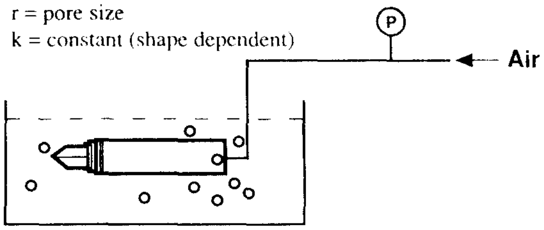


FIGURE 3:
Bubble Point Test

The bubble point method for evaluation of filter rating has been used to correlate results from glass bead tests for certain mesh filters. (Fig 3). Both the glass bead test and the bubble point test were historically reputed to provide an absolute rating for the filter media, but also implied that this was a cut-off point, in the sense that in service no particles below this size were removed, and all particles above this size were removed. (Fig 4). In addition, both methods were based on spherical particles, which only occur rarely in real filtration applications.

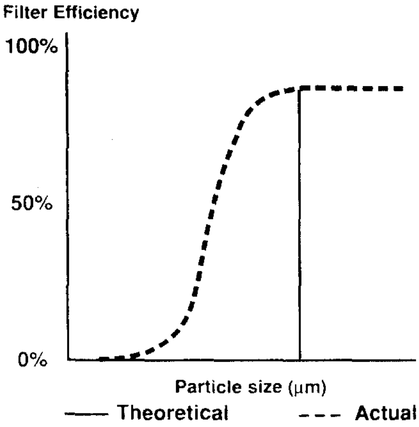


FIGURE 4:
Filter Performance

In the real world this does not occur. There is always a gradient of filter effiency in which a fraction of the particles of smaller size than the cut-off point are removed. In addition, both methods were based on spherical particles, which only occur rarely in real filtration applications.

In an effort to address these difficulties, a further test was developed, and is also included in MIL-F-8815. This has been called the "nominal rating", but the term is now so misused as to be almost meaningless. The method used in MIL-F-8815 is to challenge the test filter with a suspension of Air Cleaner Fine Test Dust (ACFTD), and to establish the micron size above which 98% of the test suspension is removed under defined test conditions. This is carried out by using an analysis membrane downstream of the filter to measure the weight of test dust passed by the filter.

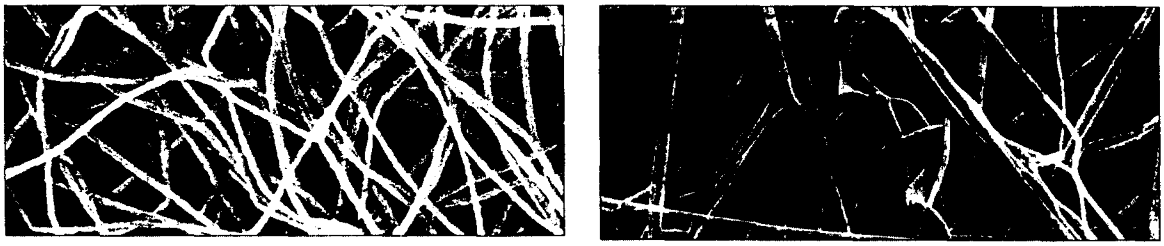
Nominal rating

1) "Based on filtration tests, 96% by mass of particles with size equal to or larger than a specified size stopped by the filter rating. Should be discouraged."
(Filtration Dictionary & Glossary - R. J. Wakeman)

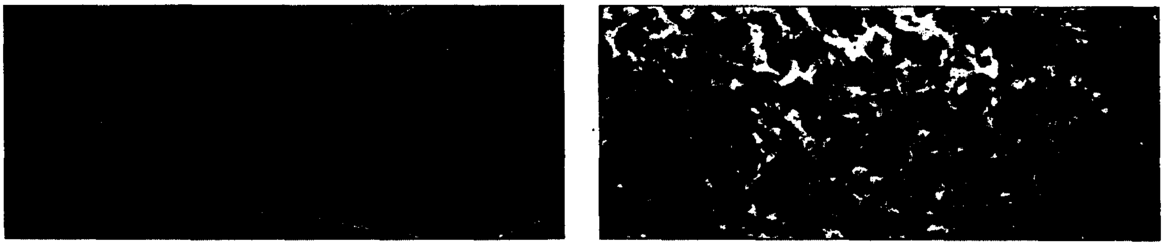
2) "An arbitary micron value assigned by the filter manufactured, based upon removal of some percentage of all particles of a given size and larger. It is rarely well defined and not reproducible."

3) "An arbitary micrometer value indicated by the filter manufacturer. Due to lack of reproducibility, this rating is depreciated."
(American National Standards Institute ANSI/B93.2/1971)

Further developments in filter media led to the use of random fibre mats, initially using cellulose fibres as in paper, but also with the later introduction of a wide range of materials, including polymeric and metallic fibres. In parallel, cast filter materials, such as nylon and cellulose acetate were also produced to provide much finer filters than had previously been achieved. (Fig 5).



Fibremetal Filter Media (x500) *Polypropylene Filter Media (x280)*



Cellulose Filter Media (x300) ***Nylon Filter Media (x3000)***

FIGURE 5: Random Fibre Filter Media

Depth Filter Cartridge

Pleated Membrane Filter Cartridge

FIGURE 6: Depth Filter and Pleated Membrane Cartridges

Filters also developed into two basic divisions - surface filters, consisting of a membrane functioning essentially as a sieve, and depth filters, where a large thickness of filter media was used to remove particulate. (Fig 6).

These developments caused a number of difficulties with the established ratings.

The assumption that all pores were close to the same size and shape was true for mesh filters, but inaccurate for random fibre mats and other cartridge filters. Consequently, the use of a distribution of glass beads to establish the single largest pore size becomes statistically inaccurate, since it is impossible to guarantee that a bead of just the largest size to pass through the pore reaches this pore before a larger bead blocks the pore.

The use of the bubble point test will still find the largest pore, but the shape of it is unknown. The influence of shape of pore on bubble point pressure can change the measured value by a factor of at least two. For depth filters the results become meaningless, as the pore size is measured on the outer surface, while the critical pore size is close to the inner core.

It can also be shown (see below) that the mean pore size has a much stronger influence on the performance of a filter in service than the largest pore (Fig 7) (Ref 3).

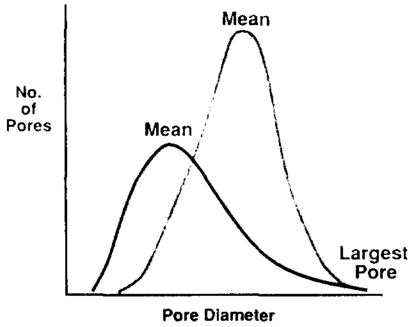


FIGURE 7: Pore Size Distribution

Filter meshes were constructed in general from metallic materials and could be regarded as fairly robust, so that the filter removal characteristics would not change as the differential pressure across the filter increased as the filter blocked. Both the glass bead test and the bubble point test provide measurements under conditions of low or no differential pressure loading.

Random fibre mats, unless rigidly bonded, are more likely to move as differential pressure increases, and consequently the removal characteristics may change.

For these reasons, these tests were regarded as inappropriate, and further test methods were developed. The bubble point test, however, is non-destructive, and consequently is used as a quality control test in filter production and filter service. Later standards for this test (Ref 4, 5) state that it is not a method for establishing a particulate removal rating of a filter.

Requirements for filter characterisation

In order to be able to predict the performance of any cartridge type filter in service a test method is required which simulates the likely operating conditions. This test must be repeatable, so that the performance of one filter might be compared with any other.

The measurements required to assess the performance of a filter are:

- the absolute rating.
- the particle removal efficiency below that rating,
- the stability of the filter with increasing differential pressure
- the relative dirt capacity.

The establishment of these parameters for a filter will allow an accurate comparison of the filter performance with the end-user requirements, so the need for trials and site evaluations is minimised. Finally the rating method must be comparable with existing methods for determining the absolute rating of a filter.

The only internationally recognised standard which determines these parameters is the Multipass Test to ISO4572 (Ref 6). This procedure was developed by the Oklahoma State University as the OSU F2 filter performance test. (Fig 8).

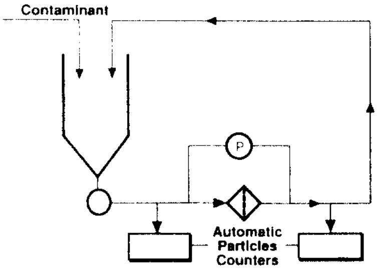


FIGURE 8: Multipass Test (ISO 4572)

This is used for the evaluation of hydraulic filters. A test contaminant is added to hydraulic oil and recirculated through the filter under test. Samples are taken from upstream and downstream of the filter for particle counting, and hence efficiency evaluation. The amount of solids added can be used to determine the apparent dirt capacity.

The test simulates the conditions a hydraulic filter would see of a recirculating contaminant in a closed loop. For most filters used in the process industries this type of operation is not applicable. Generally they are used for low viscosity fluids such as water, on a single-pass through the filters. The concern of the user is the quality of filtrate downstream of the filter after a single-pass, and the life on stream.

To enable the comparison of the performance of filters in this type of service, the principles of the multipass test have been applied to the development of a single pass filter test, using water as the test fluid.

Development of the F2 test as a standard for evaluation

The Pall F2 Test

The Pall F2 test has been developed from the multipass test to allow the rapid, semi-automated testing of filters in single pass mode using water as the test fluid. The scope of the test allows a single-pass filtration performance evaluation with continuous contaminant injection. The particle removal efficiency at a range of particle sizes can be determined, with changes over time, and at various differential pressures. In addition, the apparent dirt capacity can be measured.

To ensure a repeatable test is achieved, a uniformly dispersed contaminant, with a known and reproducible size range is required. AC Fine Test Dust is used as the test contaminant. It is dispersed in water using a mixer, then agitated using a high shear mixer for a period of 6 weeks. The result is a reproducible dispersion of particles in water.

The resulting slurry is used to challenge the test filter. The test apparatus (Fig 9) consists of a test reservoir, a pump, test filter and housing, and a clean-up filter.

Automatic particle counting systems are installed upstream and downstream of the test filter housing. A differential pressure gauge is installed across the filter housing, to monitor the change in differential pressure over the duration of the test.

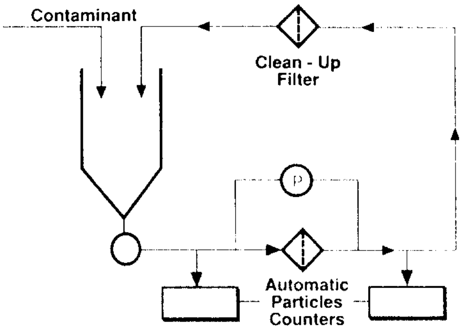


FIGURE 9: Pall F2 Test

Test procedure

1) The test is started by setting the test flow rate, through the filter housing. The generally accepted flow rate is 10 l/min/10 inch filter cartridge. The actual flow rate used will be dependant on the size of the filter, its clean pressure drop characteristics in water, and the design claims for maximum differential pressure.

2) The rig is run with only the clean-up filters, rated at 0.2µm absolute, installed. The particle counting equipment is used to monitor the background particulate level in the system. Once a low, stable level of background contaminants is achieved the test can be started.

3) The test filter is installed in a suitable housing in the system. Any air in the system is bled off.

4) The rig is restarted, so the clean differential pressure across the filter can be determined under the test conditions, with clean recirculating water.

5) The contaminant slurry is charged to a dosing tank. The actual quantity and concentration is determined by calculation from the desired test time the expected filter performance and the expected dirt capacity. From this tank it is injected into the recirculating system at a steady rate.

6) Samples are drawn off and analysed using automatic particle counters, which can count particles at up to 6 size ranges simultaneously. Samples from upstream and downstream of the filter are analysed and the results recorded automatically. The filter differential pressure is also recorded, with the flow rate. For ease of recording and analysis the data is logged automatically using a computer.

7) The test parameters (flow rate, solids loading, temperature) are held constant for the duration of the test. It is terminated at a pre-specified differential pressure.

The results recorded can be analysed by the calculation of ß ratio, or filtration efficiency as shown

$$\beta x = \frac{Nu}{Nd}$$

Where βx = filtration efficiency at x (micrometers)
Nu = number of particles of diameter x microns or larger upstream of filter per unit volume
Nd = number of particles of diameter x microns or larger downstream of filter per unit volume

A reciprocal time average of the ß ratio throughout the test is calculated for each particle size range evaluated and is generally presented graphically. The apparent dirt holding capacity can be calculated from the duration of the test, and the contaminant concentration.

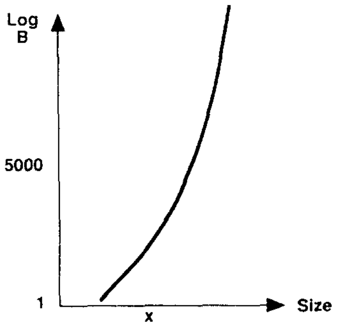
Analysis of results

Removal Efficiency

The reciprocal time-averaged beta ratios of all the size ranges measured are plotted as a graph of Log ß against Particle Size. From this graph the absolute rating can be determined. For single pass filters this is taken to be the particle size where ß = 5000, (Fig 10).

Filtration Ratio

$$\beta x = \frac{\text{No. upstream} > x\ \mu m/vol}{\text{No. downstream} > x\ \mu m/vol}$$



Time averaged to give mean value

FIGURE 10: F2 Test Results

The resulting curve shows the absolute rating and the performance below that rating. The shape of the resulting curve will also show any deficiencies in the filter. A nominal filter which exhibits unloading will give erratic, low ß ratios. Filter bypass will be illustrated by a curve which flattens out, rather than tending to infinity. (Fig 11).

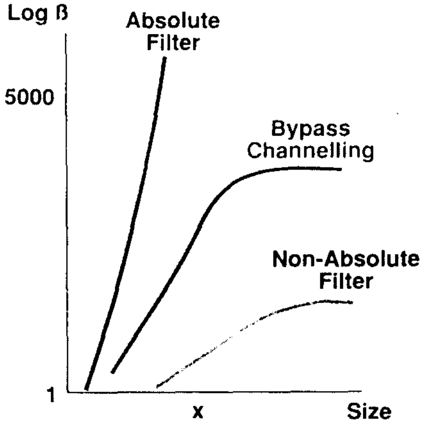


FIGURE 11: F2 Test Results Interpretation

Removal Efficiency

The apparent dirt capacity is the total quantity of contaminant added during the test, not the quantity of retained contaminant. The results for coarser rated filters will therefore be higher than for fine filters, The concentration of test dust and timespan of the test will affect the apparent dirt capacity. High dirt concentrations and/or low flow rates will cause particle bridging and cake formation, resulting in over-optimistic dirt capacity and filtration efficiency results.

Range and sensitivity

The test method described is used to evaluate filters with absolute ratings in the range 0.5µm to 25µm. The use of automatic particle counting techniques allows the accurate, reproducible evaluation of the size range of particles in the samples taken and allows a statistically acceptable average for the ß ratio to be calculated.

The reproducibility of the particle count results is determined by the performance of the sensors used, and the number of particles counted. The maximum number of particles which can be counted in a 50 cm^3 samples is about 250,000 using a particle counter. Because the size distribution of AC Fine Test Dust is biased toward finer particle sizes, the number of particle larger than a certain size will diminish as the size increases. (Fig 12).

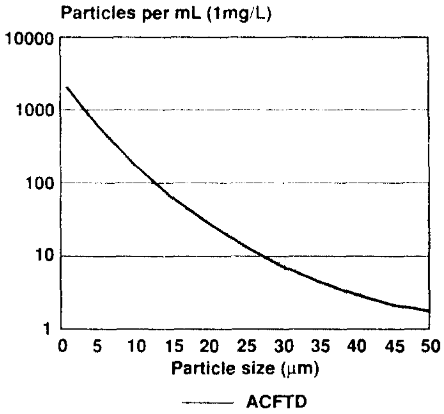


FIGURE 12: ACFTD Size Distribution (cumulative)

To obtain a statistically valid ß ratio, a count of greater than 10 particles should be measured in a downstream sample. Hence to obtain a value of ß = 5000, there must be 50,000 particles of the same size and larger upstream of the filter. At the higher particle sizes this may not be possible. The currently available particle counters are likely to become inaccurate when challenged with very high levels of particles. The value of ß = 5000 is the maximum statistically reliable value obtainable with current technology. It should be stressed that the limit on the ß ratio is governed by current particle counting technology and not necessarily by the filters under test. *A filter may genuinely remove all particles of a given size and larger. The constraint on the specification is limited by the test and available technology.* (In comparison sterilising grade filters used in the pharmaceutical industry are challenged with live bacteria, which can be detected downstream of a filter by growing colonies from single bacteria. The efficiency of detection of downstream bacteria, relative to upstream counts can be greater than 1 in 10^{14}).

The lower limit, of 0.5µm is determined by the availability of suitable particle counter sensors. Using light blockage sensors the lower limit for testing was about 2µm. The development of reliable laser scatter instruments has allowed a move to 0.5µm as the test limit.

As new technology becomes available a move to still lower size limits will be possible. The physical characteristics of the system limits the upper limit to about 25µm. Above this value the number of particles present becomes too low, there is a tendency for large particles to settle out, thus giving erroneous results.

The reproducibility of results has been found to be excellent. Different test stands have been compared by using filters which have been manufactured from the same batch of closely controlled media. The results obtained on rating have been close to the tolerances of the particle counting equipment.

Use of contaminant capacity measurement

One of the most important demands for a filter is that it should have a high contaminant capacity, and hence a long life in service.

The amount of contaminant a filter will remove in any given application is dependent on a wide range of variables. These include the size distribution and concentration of contaminants, the physical characteristics of the particles, the flux rate, and the degree of variation in the conditions. For a given application, the dirt capacity of a filter will be high if the contaminant is a hard non-deformable solid which readily forms a permeable cake. In contrast, if the same conditions are applied with a soft, deformable particulate which blinds the filter media surface, the dirt capacity and life will be much lower.

In order to be able to compare the performance of the filter, it is important to ensure that the contaminant blocks the media, and does not form a stable permeable cake (Fig 12). If cake formation did occur then the apparent dirt capacity would be unrealistically high, and the removal efficiency better than expected. The situation is identified during the test by a linear rise in differential pressure, and an improvement in the filter removal efficiency. This can be avoided by adjusting the contaminant concentration used during the filter test.

The results obtained are dependent on the test conditions (Ref 7). However, the data generated can be effectively used in the development of filter media and filter cartridge geometry and construction, to optimise the dirt capacity of the filter.

The test allows the quantifiable comparison of filters which may have the same absolute rating, but different construction geometries, to obtain the maximum dirt capacity. It should be noted that the dirt capacity values generated are only used for comparative purposes; they will not provide a quantifiable value for the amount of contaminant which will be removed from any given system by that filter.

Other test requirements

So far this discussion has concentrated on removal rating and dirt capacity. When providing information to users for filter selections there are two other areas which are of importance in any decision. These are mechanical strength and chemical compatibility.

Mechanical strength

The ability of the filter to maintain its mechanical integrity in service is a fundamental requirement of any filter. In general the operating limits can be calculated from knowledge of the materials of construction and the design. These can be confirmed by practical destruction testing. The F2 test described can be used to identify the failure point of a filter. The test is continued until the rate of change of filter differential pressure decreases. An analysis of the ß ratio data will show a reduction in filter performance as the filter fails. (Fig 13). Subsequent examination of the filter will show the mode of failure.

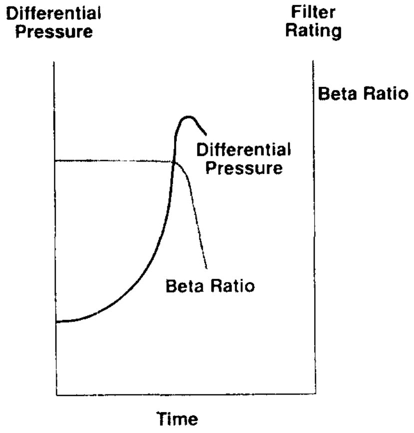


FIGURE 13: Collapse Testing

Chemical compatibility

A filter which is to be used in any aggressive chemical environment must be able to maintain its integrity and performance for the duration of exposure to that environment. It is possible to test a filter by simulating the conditions it will encounter by a soak test at the operating temperature. The effects can be determined by inspection on completion of the soak test, by measurement of changes in bubble point, and finally by conducting an F2 test on the filter, for a comparative performance evaluation against a control filter.

Limitations of laboratory tests

The benefits of laboratory test work are to allow the accurate comparison of different filters, and to quantify their relative performance. Unfortunately the requirements of a filter for a field application are rarely well defined. The specification set by a user is often vague, although it defines his requirements. "No visible particles", "optically bright" or "no haze" are often the only specifying criteria for the level of particulate removal required.

It is the combination of simple analytical techniques, such as particle size distribution analysis, gravimetric analysis and filterability tests, with the filter performance data generated in the laboratory which allows the selection of the optimum filter for any application.

The final test is always the performance of the filter in service, but the work done to characterise the filter and the application ensures an effective match first time.

Future developments

The existing test rigs allow for the testing of cartridge filters of up to about 1 metre in length, with the determination of ß ratios from 0.5µm to 25µm. The main area of development is perceived as being the downward movement of the minimum filter rating which can be measured. On-line particle counting devices with a minimum of 0.1µm are now available.

A validation programme is required to ensure the results obtained by moving to a new sensor system are meaningful, and comparable with existing equipment and data generated.

The logging and analysis of results is performed with a micro-computer. The increasing power, and reduced cost of such equipment will allow increased automation of the measurement and control processes. This in turn will enable the test parameters to be recorded, and controlled. The rapid effective analysis of data and the statistical interpretation of it should ensure that the quality of data available for evaluating filter performance allows the correct choice of filter to be made first time. It will also improve development by increasing the understanding of filter behaviour.

Conclusions

The test method which has been developed allows the accurate measurement of filter performance under conditions which closely simulate actual process conditions. The test is more rigorous than bubble point or glass bead challenge tests as the change in performance under load can be measured. It also characterises the performance of the filter below the absolute rating, so that different characteristics can be employed for different applications. A sharp cut off in performance is required for particle classification applications, such as oversize paint pigment removal, or filtering magnetic tape dispersions.

A particularly important area of use is in the evaluation of depth type filters. By their nature they cannot be effectively bubble point tested. The glass bead test is unreliable as the flow paths through the media are longer, and are more likely to block with oversize particles, giving optimistic results. With this test procedure the performance of depth filters can now be reliably quantified.

The test procedure provides users with detailed, relevant performance data for specifying the optimum filters for any application.

References

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