Cartridge Filtration Principles For the CPI

Spurred by the need for higher quality filtration and finer particulate removal, and by stricter environmental requirements, cartridge filtration has become one of the most important filtration technologies used in the process industries

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Improvements in cartridge dirt-holding capacity has led to new designs, as well as to new equations for filter selection and specification, which are linked to dramatic improvements in the time between turnarounds and filter changeout.

Cartridge filtration serves the process industries in a host of applications. Ironically, however, filtration principles are not taught adequately in many university chemical-engineering curricula, with the result that the graduate lacks sufficient skills to design or select a filtration system, whether for cartridge filtration or otherwise. In this context, "system" is indeed the correct word, because a series of fluid-particle separation steps is often required to achieve solids removal from a stream, regardless of whether the solid is the desired end-product or, instead, the impurity.

Matching filter to process

A filtration unit should be chosen so as to match particulate-removal requirements to the end use product, or to the effluent guidelines. The type of filtration used for a particular application will not always be the same, and one must closely look at the overall economics. For instance, filtration during electronic chip manufacture must meet higher quality requirements than the filtration of cooling water in a petroleum refinery. For some relatively simple filtrations, a strainer suffices, whereas in critical applications, a very fine cartridge filter is required. Depending on the nature, size and number of particulates to be removed, the filter cartridge, housing and associated pumping and companion apparatus must be sized to fit the need.

Some filtration applications may require special materials of construction. This requirement can involve the selection of both the filtration media (metal, paper, polyester, polypropylene, or others) and the filter housing itself (and ancillaries). Selection may dictate the use of corrosive resistant materials or plastics. When plastics are needed, take care that the units can mechanically withstand the pressure requirements of the process.

Matching filter to pressure

Regardless of the type of filter being used to effect solids removal, there is a widespread belief that one can continue to achieve throughput (without shutting down or backwashing) by increasing pressure on the system. Indeed, engineers normally monitor the pressure drop across the filter as a means of measuring the amount of particulates that have been removed. What engineers and technicians have not been taught, is that increasing pressure, even dramatically, might not achieve improved throughput, especially if the particle being removed is compactable. This fact of life has been proven in actual process plants on everything from plastic gels to sludge from wastewater treatment ponds. It can be quantified in terms of a pressure level, called the Tiller point (see box), where additional pressure on the filter no longer achieves any additional throughput.

Filtration basics

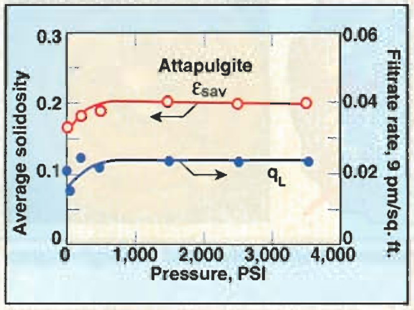
During filtration in cartridges, certain types and sizes of particles suspended in the liquid are allowed to pass through the filter media while the "boulders" are filtered out. (Dissolved solids generally cannot be removed by filtration without some form of pretreatment.) In water filter systems, for example, engineers can turn to filter cartridges to remove fine particles. A cartridge can typically address the particle size range between 0.5 and 70 microns. (A micron represents 0.001 millimeters, or 0.000039 inches; the smallest particle that can be seen by the unaided eye is 40 microns in diameter.)

The basic mechanisms of filtration (Figure 1) are inertial impaction, diffusional interception and direct interception. Since the density of a particle is typically closer to that of a liquid rather than that of a gas, direct interception is the desired mechanism for separating particles from liquids.

By combining the direct interception mechanism with particle bridging theory, we are able to explain why a filter medium with specific size pores or openings is able to capture particles with smaller diameters than those of the pores. According to classic bridging theory, a stable bridge will form over a pore if two or more particles with diameters at least one half that of the pore diameter contact the opening at the same time. This newly

THE TILLER POINT

In pressure cake filtration, it is normal to expect to receive higher filtration rate and cake density by increasing operating pressure. This is true for incompressible and only moderately compactible material. However, for highly compactible materials, such as flocculated, fragile, or very fine particles, the filtrate rate and average cake solidosity reach maximum values when pressure continuously increases as shown in the following figure. A critical pressure drop beyond which there is little effect of pressure on either the flow rate or average cake solidosity is defined as the Tiller point. Theoretically, the Tiller point is defined as the pressure at which the filtration rate reaches 90% of its maximum value



In operation, when the Tiller point is reached, a constant-flow-rate or expression should be applied for further filtration rate or average cake solidosity increasing.

The relationships of filtrate rate q and average cake solidosity ε_{sav} with pressure are developed by Tiller as shown in the following two equations:

$$q = \frac{p_\alpha}{\mu \varpi_c \alpha_o (n-1)} \left[1 - 1\Big/\left(1+\frac{\Delta p_c}{p_\alpha}\right)^{n-1}\right]$$

$$\varepsilon_{sav} = \varepsilon_{so}\left(\frac{\delta-1}{n-1}\right)\left[\frac{1-1/(1+\Delta p_c/p_\alpha)^{n-1}}{1-1/(1+\Delta p_c/p_\alpha)^{\delta-1}}\right]$$

In which

ω_c – volume of cake solids per unit area, m^3/m^2,

Δp_c – pressure drop across cake, Pa

p_α, α_o, ε_{so} – empirical parameters

n, δ – cake compactibility parametersers

These equations show that for incompressible materials (n and δ =0), and moderately compactible materials (n and δ smaller than 1), increasing DPc will lead to increase of q and ε_{sav}. However, for highly compactible materials with n and δ greater than 1, when pressure drop across cake Δp_c increases and reaches infinity, the flow rate and the average cake solidosity reaches their maximum values:

$$q\max = \frac{p_\alpha}{\mu \varpi_c \alpha_o (n-1)} \qquad \varepsilon_{sav}\max = \varepsilon_{so}\left(\frac{\delta-1}{n-1}\right)$$

The Tiller point can be calculated based on its definition and the four equations ❑

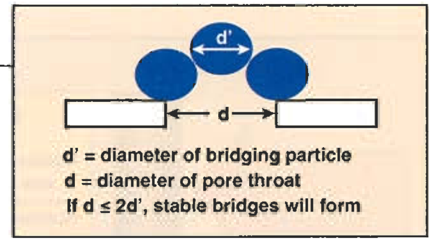


FIGURE 2. Bridging enables pores to retain particles of smaller diameter than than that of the pore

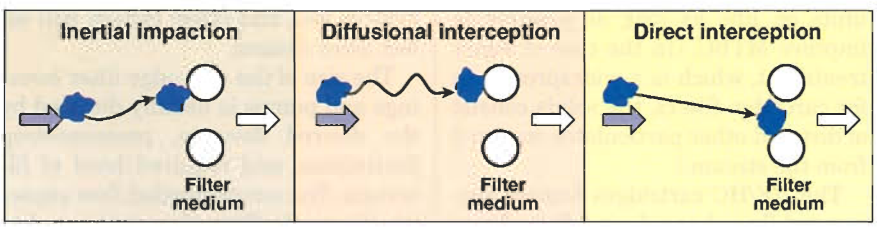


FIGURE 1. Of the three basic mechanisms of filtration, direct interception works most effectively for liquid-solid separation

formed bridge (Figure 2) contains even smaller pores that, in turn, capture smaller particles.

Under certain conditions, collected particles can inadvertently become released from the filter medium and pass downstream. Variations in flowrates and pressure surges, are common causes of particle release. Even under ideal flow conditions, filters can release particles if their medium structure is subject to pore enlargement. This is a typical occurrence in string-wound filters and low-density felt bags whose pore sizes change in response to increased pressure. The best filters are designed with filter media that have fixed pore structures that are not affected by variations in pressure and flowrate, as discussed in the next section. These facts are particularly important in cases where increased pressure may force flexible particulates through the filter instead of removing them.

Cartridge filter types

The most commonly used cartridge filters in process filtration can be classified as having either a non-fixed random-pore-size medium or a fixed controlled-pore-size medium. Understanding the differences between these two types is important in predicting how each of these filters will perform during the filtration process.

Non-fixed random-pore-size medium filters, such as felts, woven yarns or packed fiberglass, are constructed of media that contain pores of various dimensions that can enlarge as flowrate and differential pressure change. These types of filters are subject to particle unloading, channeling, and media migration.

Filters that instead have media with the fixed controlled-pore-size are fabricated in a way that prevents the pores from enlarging under changes in pressure or flow. Although these filters contain pores of varying sizes, their overall pore structure is controlled during manufacture to assure quantitative removal of particles larger than a given size. With this type of filter, any particles released during impulse conditions can be expected to be smaller than those designated by its removal rating.

Removal ratings

Various systems for rating removal efficiency of cartridge filters exist today. Two of the most common are the nominal rating and the absolute rating systems. Unfortunately, each manufacturer is free to employ variations of the different testing procedures to assign the nominal or absolute ratings of their specific filters.

A nominal filter rating is generally defined as an arbitrary micron value based upon particle removal by weight of some percentage of all particles of a given size or larger. Common percentages used by various manufacturers include 98%, 95%, and 90%. This rating system bases its results on gravimetric testing rather than actual particle counting. Problems associated with the nominal rating system include: a poorly defined test procedure, the fact that the removal percentages may vary with manufacturer, and the fact that test data are not usually reproducible — in fact, it is not uncommon to find downstream particles larger than the micron rating of the filter.

An absolute filter rating is generally defined as the diameter of the largest hard spherical particle that will pass through the filter under specific test conditions. Several recognized tests exist for establishing the absolute rating of a filter and the choice among

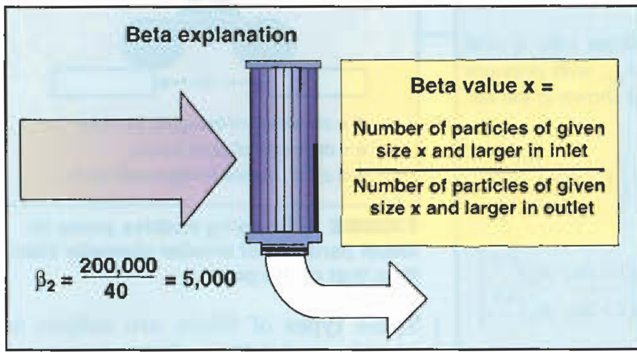


FIGURE 3. Beta ratios, though developed for use with oils, can be useful in a wider context

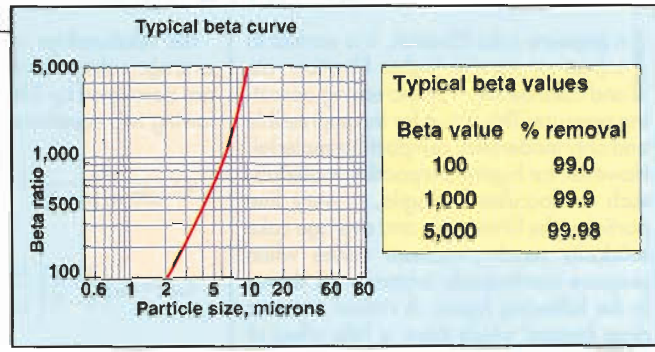


FIGURE 4. The Beta curve captures a given filter's efficiency across the range of particle sizes

them may vary with manufacturers. However, in all tests, the filters are subjected to a particle challenge by pumping a known contaminant through the filter and measuring upstream and downstream particle counts. Only filters having a fixed controlled-pore-size medium filters can have absolute ratings.

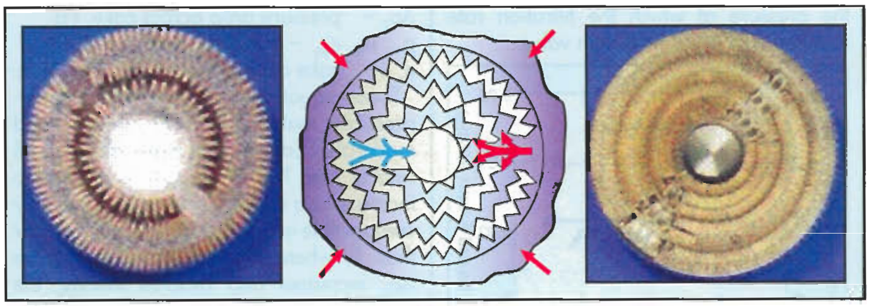


FIGURE 5. A staged, pleated filter configuration is commonly used for high-capacity cartridge filters

Beta ratios

Beta ratios were originally developed for evaluating the performance of filters for hydraulic and lubricating oils. Today, these ratios (Figure 3) can be very useful in measuring and predicting the performance of absolute rated filters under specific test conditions in a variety of liquids.

The Beta ratio concept involves measuring total particle counts at several different micron levels in both the influent and effluent streams. These counts provide a profile of the filter efficiency at the different micron levels and can be plotted as a Beta curve (Figure 4) for the given filter. For a detailed discussion of Beta ratios, see "Predict Filter Performance With Beta Ratios," *CE*, August 2005, pp. 44–46.

Filter selection

Factors that must be taken into consideration when choosing a filtration system include: chemical and temperature compatibility, ability to accommodate the process flowrate, an acceptable pressure drop, the required degree of filtration, and the overall filtration cost. In state-of-the-art filtration systems, the filter cartridges are almost always pleated. Furthermore, state-of-the-art cartridge technology is largely based upon relatively new types of filters known as high capacity cartridge filters (HCFs).

HCF cartridges generally utilize a staged, pleated filter that offers high efficiency and high capacity (HE/HC); these propereties maximize solids-holding capacity in order to assure maximum time between change out (MTBC). Keep in mind that the filtration operation in industrial plants can be tied to handling hazardous solutions, so producers try to keep the units on line as long as possible to improve MTBC. (In the case of water treatment, which is a widespread use for cartridge filters, the solids consist of dirt and other particulates removed from the stream.)

The HE/HC cartridges feature segregated flow channels and flow chambers to optimize the Alpha Factor (Å) – a factor, defined below, that is the key to determining total cost of filtration operations. Combining this segregation-based design with the technique of pleating several different filter media together in a single pleat pack maximizes solids-holding capacity. This design permits the use of many different types of filter media. This capability is essential for a wide range of fluid and temperature applications. A cross sectional view (Figure 5) shown above details the basic design and flow paths of an HE/HC filter. This unique design works with either an "outside in" or an "inside out" flow path and is not limited to three rows of media.

Since process streams vary in composition and contaminants (indeed, this is true even with respect to water streams to be purified), it is difficult to designate a filter medium that is suitable for every purpose. (Other complications can arise from the glues and seals used in filter construction.) Generally, polypropylene is acceptable. However, extreme operating temperature, presence of hydrocarbons in the system. pH, and other factors will affect filter choices.

The size of the cartridge filter housings and pumps is usually dictated by the desired flowrate, pressure-drop limitations, and required level of filtration. The recommended flow capacity of a single filter element is used to determine the total number required for the desired flowrate. Housing size relates directly to the number of filter elements. Sufficient pump pressure must be provided to permit the desired flowrate through the filter element as it plugs, so as to fully use the effective dirt holding capacity of the filter.

Filtration costs

A detailed analysis is needed to understand the true cost of the filtration operation. While most engineers understand capital costs, it is also necessary to cover the true cost of operations and maintenance of the filtration system.

Total filtration costs must include both the capital cost and the daily costs to operate the system. The latter includes changeout time, cleanup and downtime, not to mention the cost of labor, of installing and removing the element, and the actual costs of disposing of the element. In those cases in which disposal requires special breathing apparatus and protective clothing, the actual cost of the total filtration operation can be quite high. The cost of the filter element itself may be nominal in comparison.

Filtration cost efficiency (E) is defined as the total costs, direct and indirect, that are associated with removing one pound of solids from a process stream. Direct cost is filter price and indirect costs include labor and disposal. A lower total cost results in a better efficiency rating. If we disregard equipment depreciation, we can express this relationship by the following formula:

$$E = \frac{P}{H} + \frac{L}{H} + \frac{D}{H}$$

D = Disposal cost/filter
H = Dirt holding capacity, lbs.
L = Labor cost/filter
P = Filter price

In cartridge filtration – which is commonly a continuous operation – one must recognize it is important to maximize the actual dirt holding capacity, in pounds (H) of the operating filter. Using a filter with low dirt loading capabilities can dramatically increase the true cost of the filtration operation. However, by knowing dirt loading, you size the filter accordingly. As indicated earlier, one matches the filter and housing to the flow rate, amount of liquid to be filtered, the particulate removal requirements, and the dirt holding requirements.

Filter price and dirt holding capacity are the dominant components in operating cost. The relationship between these two items is defined by the aforemenioned Alpha Factor (Å):

$$\text{Alpha factor } (\AA) = \frac{\text{Filter price } (P)}{\text{Dirt holding capacity } (H)}$$

Combining the Alpha Factor formula with the Filtration Cost Efficiency formula provides an interesting result.

$$E = \AA + \frac{L}{H} + \frac{D}{H} \Rightarrow E = \AA + \frac{L + D}{H}$$

The indirect costs shown in the equation are reduced as the dirt holding capacity of the filter increases. Therefore, the Alpha Factor becomes the dominant number in the equation. The lowest Alpha Factor results in the lowest filtration cost. One can see that wide variations in H dramatically offset Å in order to achieve a given filter cost efficiency (E). One consequence: for applicationa involving small batches, one does not necessarily maximize filter life.

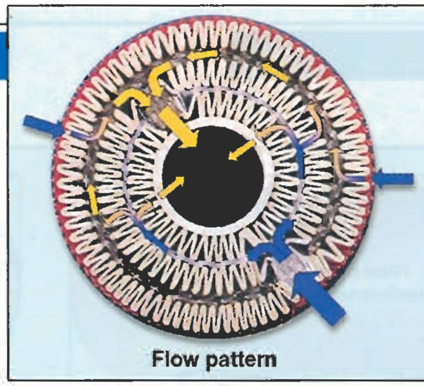


FIGURE 6. Large-diameter, pleated filter cartridges are becoming the norm in state-of-the-art filtration systems

New technology affects filter selection

In state-of-the-art filtration systems, large-diameter pleated filter cartridges are replacing standard cartridges and non-pleated bags, as mentioned above. One design of these larger cartridges utilizes a series of segregated flow channels and flow chambers to maximize the effective surface area of the pleated filter media within each cartridge. The cross sectional view shown above (Figure 6) details this basic design, which is not limited to the three rows of media shown in the figure.

Depending upon the flow rate and contaminant loading, these systems will use one of the following cartridges:

- 6.25-in. O.D. high capacity filter (HCF)
- 12.75-in. O.D. ultrahigh capacity filter (UHCF)
- 20.0-in. O.D. ultra capacity filter (UCF)

The recommended flow capacity of a filter element is used to determine the total number of housings required for the desired flow rate. Housing size relates directly to the number of filter elements.

Maximizing filter life

Filter life is directly related to a filter's dirt holding capacity. It can be defined as the total volume of fluid that passes through a filter before the filter reaches its maximum operating differential pressure.

Under a constant flowrate, the life of most absolute-rated filters is significantly increased when their effective surface areas are increased. This property of filter life is a direct result of the relationship between flow density (gallons per minute per square foot) and the resulting differential pressure across the filter area. Under ideal conditions the maximum increase in filter life is proportional to the square of the increase in effective surface area. Doubling the effective filter surface area can increase filter life up to four times. (Figure 7).

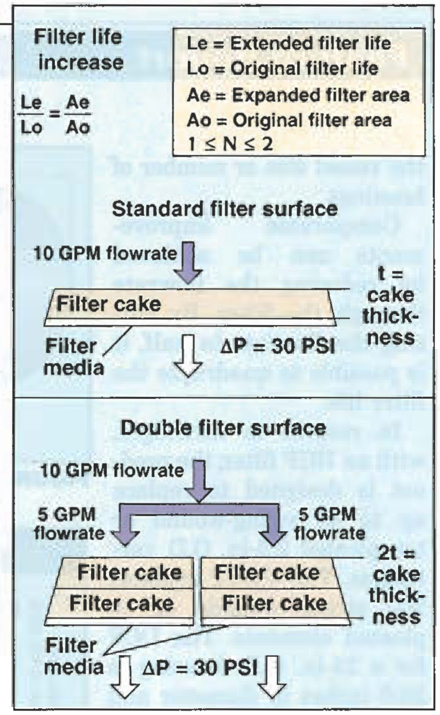


FIGURE 7. Note the benefits attainable from increasing the effective filter surface

An easy way to increase filter life using an existing housing is to replace depth filters with pleated filters. In the following diagrams,it can be seen that the surface area of the cylindrical depth element is much less than that of the pleated element. (Figure 8).

Especially in large-scale process filtration, design and specification engineers should obviously consider the savings associated with filter housing costs. This is particularly true if high alloy metals are used as the material of construction. Many plants design their filtration systems based on a maximum flowrate. If a 2.-in. OD or 3.75-in, OD cartridge is used in the base flowrate calculations, a larger vessel will be required to meet the maximum flow requirements.

An alternative is to increase the actual number of filters by increasing

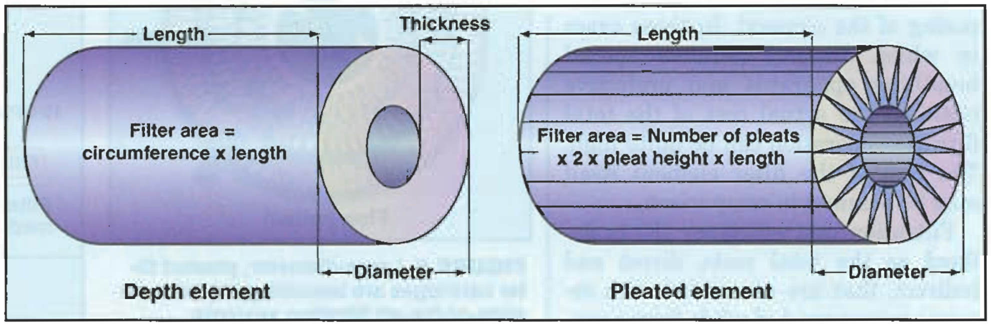


FIGURE 8. Pleated filters provide much more surface area than do cylindrical depth elements

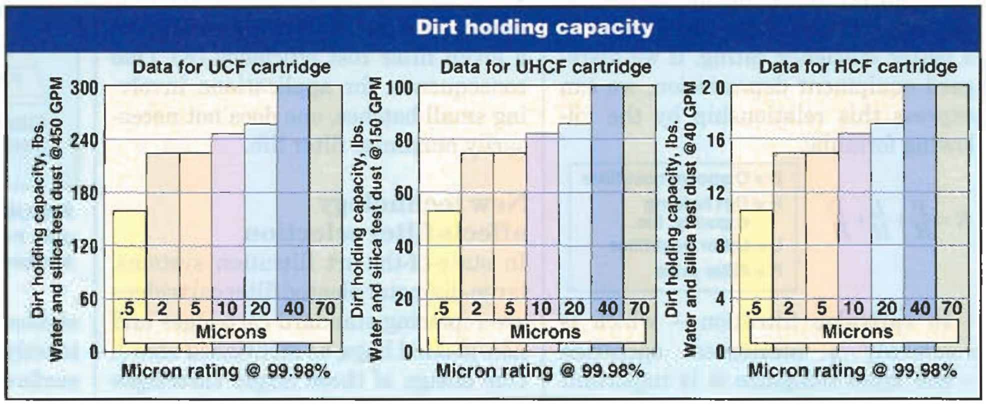


FIGURE 9. The differences in dirt-holding capacity for UCF, UHCF and HCF cartridges are dramatic

MAXIMUM NUMBER OF CARTRIDGES FOR VESSEL ID				
Vessel ID, in.	2.5 in. O.D. standard cartridge	6.25 in. O.D. HCF cartridge	12.75 in. O.D. UHCF cartridge	20.0 in. O.D. UCF cartridge
15	19	3	1	0
22	40	7	1	1
28	70	12	3	1
36	120	19	5	1

the vessel size or number of housings.

Comparable improvements can be achieved by reducing the flowrate through the filter. By cutting the flowrate in half, it is possible to quadruple the filter life.

In respect to cartridges, with an HCF filter, the product is designed to replace up to 40 string-wound or ten pleated 2.5-in. O.D. cartridges. The UHCF replaces 200 string wounds or 50 pleated elements. The UCF for a 24-in. O.D. housing is 20.0 inches in diameter and replaces 600 string wounds or 150 pleated elements (Figures 8 and 9).

Constructed to fit most standard cartridge housings with minor, if any, hardware modifications, HE/HC filters provide a very cost-effective method of maximizing effective surface area in existing housings.

When one considers capital spending costs for new installations, the savings associated with filter housing costs is equally important. Using a HE/HC design will minimize the filter vessel size (and costs) required for specific flow rates and can result in significant cost reductions when high-pressure filter vessels are required.

Also, it is imperative that daily testing of the process stream (using sample ports) be conducted. Testing is critical in identifying when upset conditions exist within the process.

In summary

Filtration (cartridge or other) in the process industries deserves close attention because total costs can be significant. The filter operation can easily become the most important factor in the quality and cost of the end product. It is not unusual for filtration costs to rival energy costs in certain critical applications, especial in very fine particulate removal in the sub micron area.

Cartridge-filter elements used in process systems should be selected based on particulate removal requirements and dirt holding capacity. Select media that contain fixed controlled pore sizes.

Beta ratios provide a profile of a filter's efficiency at various micron levels.

Total filtration operating cost must include equipment depreciation, filter element cost, labor cost for element change out, downtime and element disposal cost. It is critically important to understand the issues and costs related to filters used in toxic and hazardous service.

A filter element's Alpha Factor (Å) is easy to calculate. The lowest Alpha Factor results in the lowest filtration cost.

An increase in effective surface area or a reduction in flowrate will result in a significant increase in filter life.

Quality control is essential for either batch or continuous filtration systems. ■

Edited by Nicholas P. Chopey

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