FUNDAMENTALS OF LIQUID-SOLIDS FILTRATION

FTC®

FLS-1.0

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1. Introduction

What is Liquid-Solids Filtration?

Liquid-solids filtration is the common term used for solid-liquid separation, which is a subcategory of fluid-particle separation. Fluid-particle separation can be broken down into the following subcategories of separation of particles from fluids.[1]

- Solid-Liquid Separation (a.k.a. Liquid Filtration)
  - Solid-Liquid Filtration
  - Solid-Liquid Separation
- Gas-Liquid Separation (a.k.a. Air Filtration)
  - Solid-Gas Filtration
  - Solid-Gas Separation

Liquid filtration is defined as the process in which solid particles are removed from a liquid using a filter medium. The filter medium is porous, allowing for the fluid to pass through the medium while retaining the solids on the surface or in the depth of the medium. By comparison, solid-liquid separation does not utilize a filter medium. The same applies to solid-gas separation. In general, filtration utilizes a filter medium whereas separation does not utilize a medium.

Below is a general breakdown of solid-liquid separation equipment categories by filtration mechanism.

Filtration	Separation
Straining	Gravity Settling
Cake Filtration	Centrifugal Settling
Depth Filtration	Flotation
	Others (e.g., electrical field)

Each category listed has many subcategories, and each of those categories can have a multitude of technologies and equipment. In other words, solid-liquid filtration and separation is an extremely broad and complex topic. The purpose of this technical report is to focus solely on industrial cartridge filtration, which is one type of straining filtration technology available to those processing liquids.

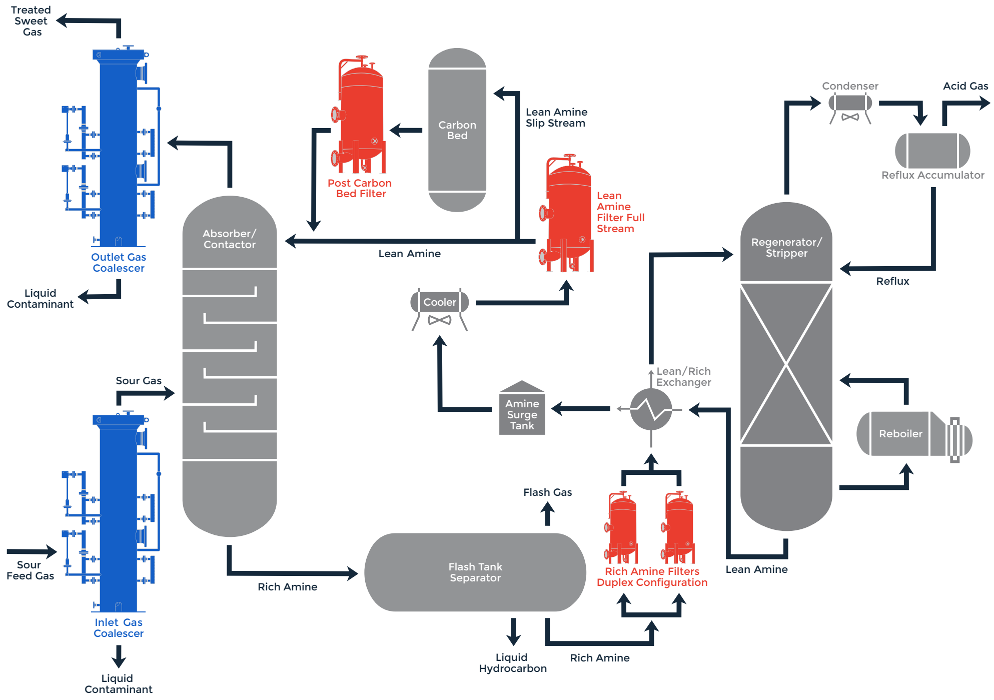
2. Overview of Industrial Cartridge Filtration

When a new process is being developed, seldom is liquid filtration the primary concern. The focus is primarily on maximizing product yield, minimizing unwanted byproducts, meeting stringent safety and environmental requirements, and maximizing return on investment of the process. However, liquid-solids filtration is used in every industrial facility where a liquid is directly or indirectly part of the process because solid contamination control significantly impacts process economics. Solid particulates in a fluid process stream can result as part of chemical reactions in these processes or as a by-product of corrosion and erosion in piping, equipment and tanks. The operational stability of industrial plants and the longevity of expensive process equipment is largely dependent on the mitigation of contaminants through reliable solids management. Proper solids contamination management with a properly sized filtration system can eliminate costly problems such as those listed below.

- Reduced value of final fluid due to poor quality
- Reduced production rates
- Increased maintenance costs
- Frequent downtime
- Equipment fouling
- High replacement part costs
- Increased corrosion rates of piping and equipment due to under-deposit corrosion
- Erosion of process equipment
- Ineffective process efficiencies resulting in off-spec products
- Increased scrap rates of finished products
- Unreliable operations
- Loss of valuable solid product (e.g., catalyst and gold, among others)

The impact of ineffective, undersized or inefficient liquid-solids filtration equipment on a plant's operations is extremely costly and supports the need for efficient, reliable filtration equipment. While disposable filters entail continued use and filter expense, they allow a plant to continue operating with reduced maintenance and system operating expenses. The reductions in system operating expense and process stability easily outweigh the cost of filters.

Due to the importance of liquid filters, they are part of almost every fluid process. For example, natural gas processing facilities and refineries use treatment solvents to remove acid gas components from gas streams. Amines such as MDEA, DEA, MEA and specially designed formulations absorb hydrogen sulfide (H_2S) and carbon dioxide (CO_2) to "sweeten" the gas stream. These gases cause corrosion and are harmful to humans, downstream processes and the environment, making their removal critical. A standard amine sweetening unit process flow diagram is shown in **Figure 1**. Although filters are not the key process equipment sweetening the gas, they are essential and facilitate a reliable and efficient process by removing unwanted solid contaminant. Without removing the contaminant, the process becomes inefficient and possibly ineffective due to the contaminant promoting foaming, fouling equipment and reducing efficient heat transfer.



Full Amine System Process Overview

Figure 1

Amine solvent system process flow diagram

Another example of liquid filtration equipment is on a hydrotreating process shown in **Figure 2**. Hydrotreaters are units within refineries that use hydrogen and catalyst to remove impurities such as sulfur from petroleum cuts. Hydrotreater catalysts are composed of a porous alumina support with a coating of metallic sulfides and will be around 1/16” in diameter. Common applications include gasoline, naphtha, kerosene and gas-oils, as well as biofuels, which will present a broader range of applications and challenges. The purpose of feed filtration in a hydrotreater is to prevent fouling of the reactor catalyst bed. Protecting the catalyst bed by providing reliable and predictable effluent fluid quality is the primary goal of any properly designed filtration system. For hydrotreating units, the feed filter provides a sacrificial system that removes undesirable contaminants that cause reactor fouling. A well-designed feed filter system will prevent problems in hydrotreater applications by allowing the reactors to reach full catalyst life and enter scheduled turnarounds as planned.

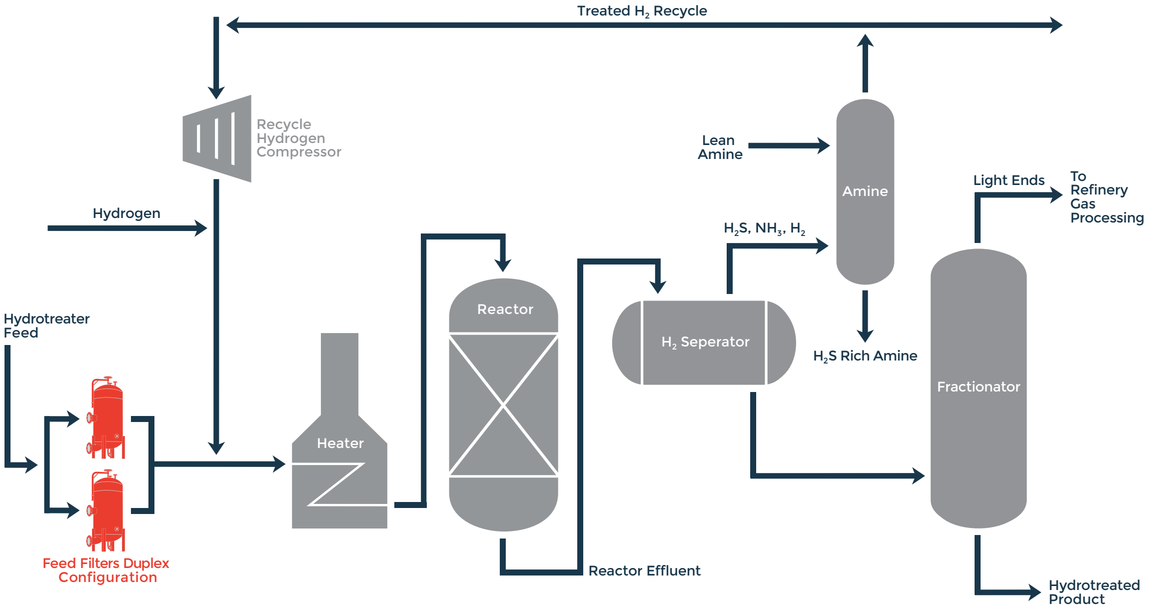


Figure 2

Hydrotreating process flow diagram

The use of industrial cartridge filters is not limited to these specific applications, refining or gas processing. These are just two common examples provided to demonstrate how a filter can be used. There are many applications for filter cartridges in every market. Every man-made product that started in gas or liquid form has likely been filtered at some point in its life cycle.

Other examples of applications are:

- Final clarification of fluids for custody transfer or sale
- Recovery of expensive catalysts or valuable solid product
- Protection of spray nozzles
- Filtration of lubricating oils and machine coolants
- Filtration of drinking water and other beverages
- Filtration of chemicals in mining operations
- Filtration of chemical plating solutions
- Filtration of process water (e.g., pre-RO, steam condensate, closed loop cooling systems)
- Filtration of water to meet environmental regulations for disposal

Figure 3 shows a typical liquid filtration vessel, and Figure 4 shows some common liquid filter cartridges.

Figure 3

FTC's Torrent Cartridge Filter Vessel

Figure 4

FTC liquid-solids cartridge filter elements

3. General Overview of the Process of Liquid-Solids Cartridge Filtration

Before we get into the scientific principles of filtration, one must understand the basic operations of a liquid-solids filtration system. A simplified schematic is provided in **Figure 5** below.

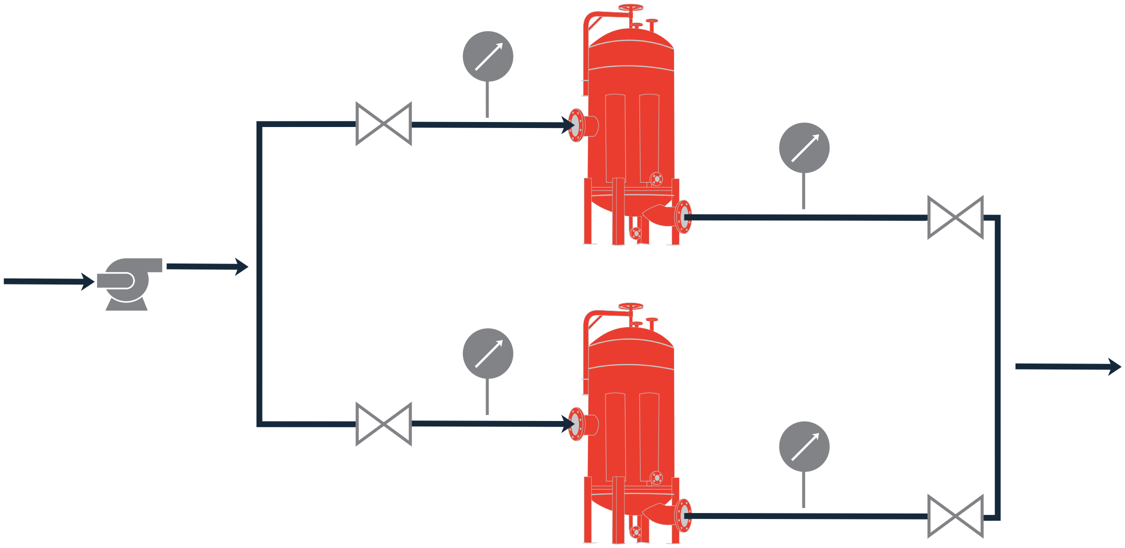


Figure 5

Example of a basic liquid-solids filtration system

Liquid flow is typically introduced to the filtration system by an upstream pump, but other methods to create liquid flow can be used such as gravity or vacuum. The dominating method of producing liquid flow is by a pump. The upstream pump delivers the liquid slurry to the cartridge filter housing through piping or hoses in some temporary cases. Due to the pressure losses caused by the resistance in the piping, changes of section through orifices and the torturous path of the filtration media, the pump is designed to provide enough pressure to overcome all these anticipated pressure losses and still maintain the desired flow rate to the downstream process. It should be noted that every filter element and every filtration housing has a recommended flow rate, defined as the liquid volume per unit of time.

The slurry, commonly called influent, enters the filtration vessel through the inlet nozzle and enters the dirty chamber of the housing. The slurry is forced through the filtration medium due to the pressure differential across the filter media. The clean side – the outlet side – will have a lower pressure than the inlet, and the fluid will take a path of least resistance towards the clean side. As the slurry passes through the filter medium, the solid contaminant is retained in the medium and the clean fluid, passes through the clean chamber of the filter vessel and then exits through the outlet nozzle. The clean fluid is commonly referred to as the effluent.

The filter's service life is determined by differential pressure and is monitored by plant operations. Every filter has a recommended maximum differential pressure, also known as the terminal differential pressure, which is defined by the filter manufacturer. This tells the end user at which point the filter medium is loaded with contaminant and ready to be changed. Plant operations might assign its own terminal differential pressure, but it should never exceed the manufacturer's recommended maximum. Filtration housings will have an inlet pressure gauge port and an outlet pressure gauge port. Inlet and outlet pressure gauges or a differential pressure gauge are connected to these ports for monitoring. Once the filtration system reaches terminal differential, the operators follow their changeout procedures to change filters. This usually involves the following: diverting flow from the housing, lock-out-tag-out procedure on the valves, depressurizing the housing, draining the process fluid, flushing any unsafe fluid or vapors from the housing, opening the closure to access the filter elements, removing and properly disposing of the cartridges, installing the new cartridges and securing the housing closure in preparation of safe introduction of the process fluid for continued operations. In most applications, there is a secondary filter housing of the same design piped in parallel so the flow stream can be diverted to this housing and so filtration of the process fluid is not interrupted.

4. Principles of Filtration

a. Particle Capture Mechanisms – Fiber and Filter Medium

In filtration, a filter medium is used to capture the solid particle contaminant. In liquid-solids cartridge filtration that medium is a matrix of fibers which can be as small as submicron in diameter. The particle must come into contact with a fiber in order to be trapped by the filtration medium. The mechanisms by which particle capture on a fiber occurs is well-known. Particle capture on a fiber proceeds by way of the following primary mechanisms, as illustrated in **Figure 6**.

- Diffusion deposition – The trajectories of individual small particles do not coincide with the streamlines of the fluid because of Brownian motion. With decreasing particle size, the intensity of Brownian motion increases, as does the intensity of diffusion deposition.

- Direct interception – Under this mechanism, a particle is intercepted as it approaches the collecting surface at a distance less than or equal to its radius.

- Inertial impaction – The presence of a fiber in the flowing fluid stream results in a curvature of the streamlines in proximity to the fiber. Because of their inertia, individual particles do not follow the curved streamlines but are projected onto the fiber and may deposit there. The intensity of this mechanism increases with increasing particle size and velocity of flow.

- Gravitational deposition – Individual particles have a certain settling velocity due to gravity. Consequently, the particles deviate from fluid streamlines and may contact a fiber.

- Electrostatic deposition – Both particles and fibers in the filter typically carry electric charges. Deposition of particles on the fibers may take place because of the forces acting between charges or induced forces.

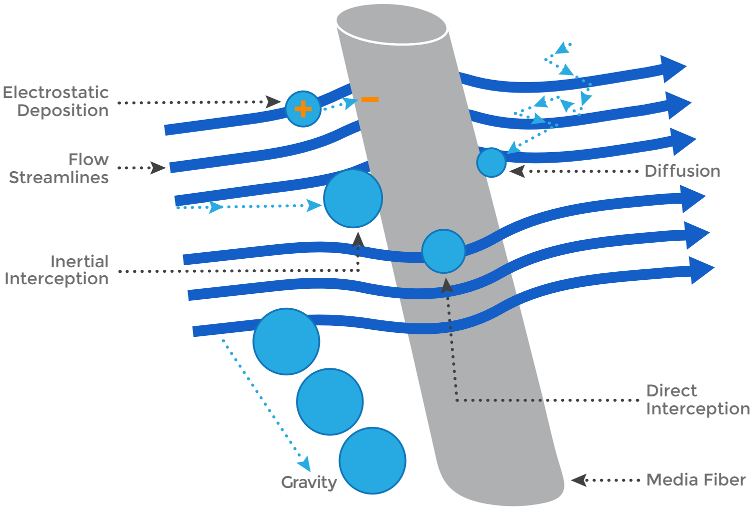


Figure 6

Primary mechanisms of particle capture on a fiber

In liquid filtration, the primary mechanism of particle entrapment by a filtration medium is by straining, also known as surface straining. **Figure 7** provides an illustration of straining. The particles are simply larger than the pores created by the fibers, which collectively makeup the filter media matrix. For example, a 20-micron particle cannot fit through a 10-micron pore. It will be trapped on the surface of the pore. Most media are not infinitely thin. They are three-dimensional with a significant number of pores (depending on fiber size and count) that can vary in size and can vary through the depth of the filter medium. If the particle penetrates the surface of the filter medium and it moves through the medium or through a pore until it meets a point where the pore is too small, then it is termed depth straining.

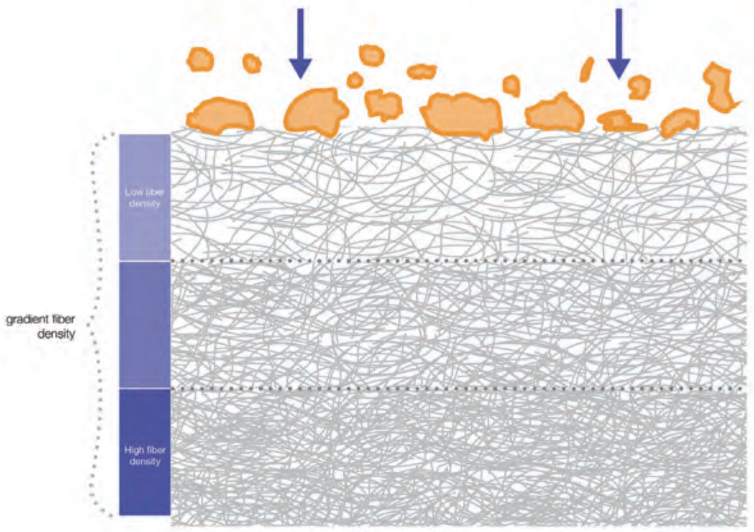


Figure 7

Illustration of surface straining

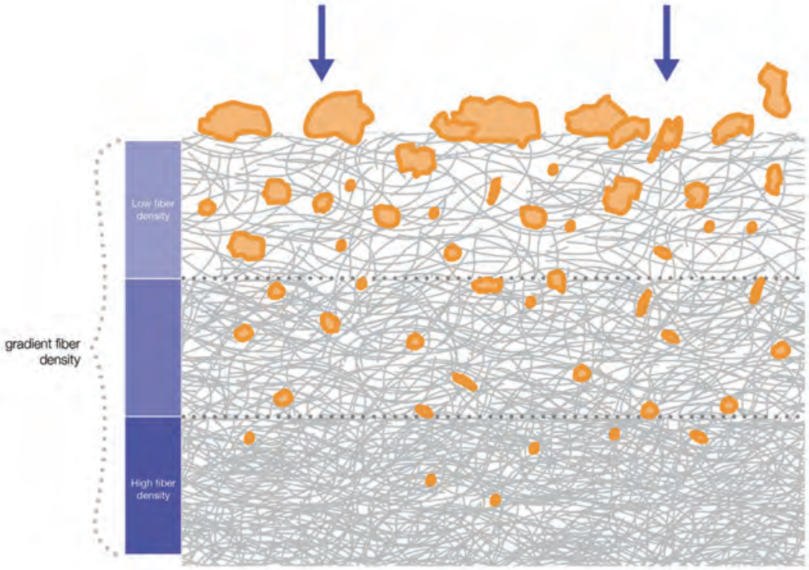


Figure 8

Illustration of depth straining

In addition to fiber capture mechanisms, surface straining and depth straining of particles by the fiber matrix, particles can be trapped by the other particles that build up on the surface of the media. One common method is particle bridging. If a high enough concentration of solids is entering the filter medium and two or more particles try to pass through a pore at one time, they can effectively get trapped as if they were one larger particle. For example, if two 10-micron particles try to pass through a 20-micron pore at the same time, they will be filtered by straining because they act as one 20-micron particle.

Figure 9 illustrates the particle bridging theory. If the two particles have a diameter equal to or greater than half of the pore throat, a stable bridge will be formed. If the bridging particles have a diameter less than half of the pore throat, an unstable bridge will be formed. It would take more than 'two' small particles to form the bridge if they are smaller than half the pore throat. If the bridge is unstable, the bridge can potentially collapse, and the particles can end up downstream. Research shows that particles as small as 1/7th- 1/13th the size of the pore throat can get bridged.[2]

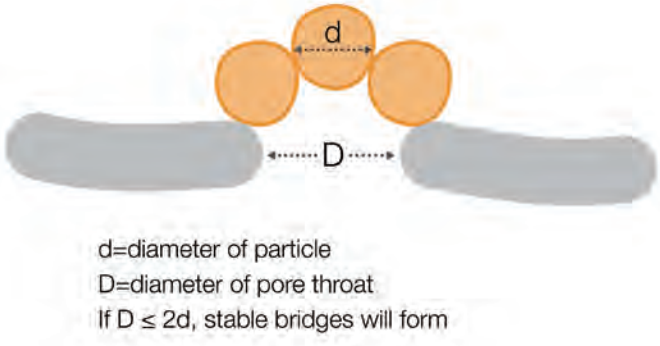


Figure 9

Illustration of particle bridging

Another method of particle entrapment is through cake formation leading to cake filtration. Once a considerable number of particles build up on the surface of the media, they start to touch. These particles do not fit tightly together like a jigsaw puzzle, so there are typically open gaps for fluid to flow between them. As the fluid stream flows through the particles, the particles act as a filter themselves, and they trap more particles. This is referred to as cake formation or caking. See **Figure 10**. At this point, the filter cake becomes the primary mechanism of filtration since the apparent pore size created by the particles in the cake are less than that of the filter medium itself. As a result, the filter becomes more efficient as the cake builds. This is demonstrated in **Figure 11**.

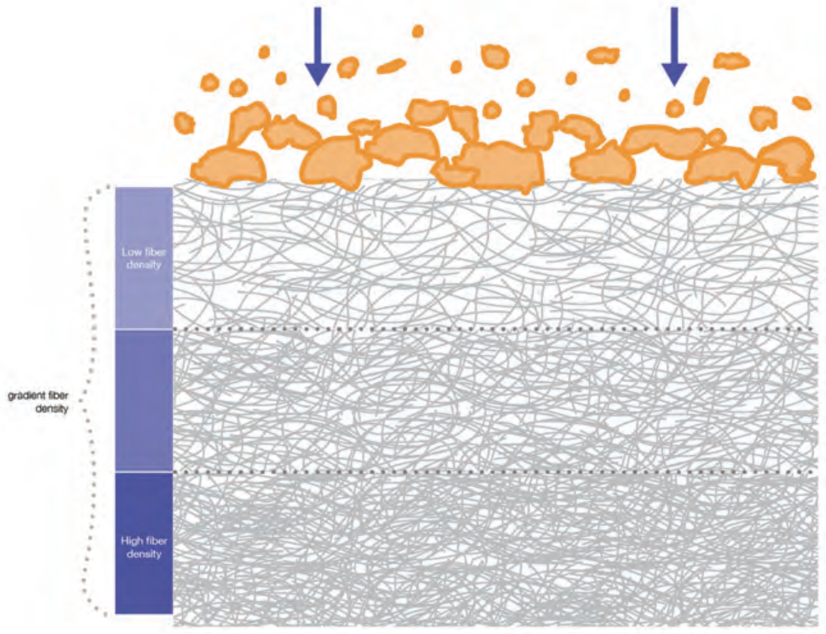


Figure 10

Illustration of cake formation (caking)

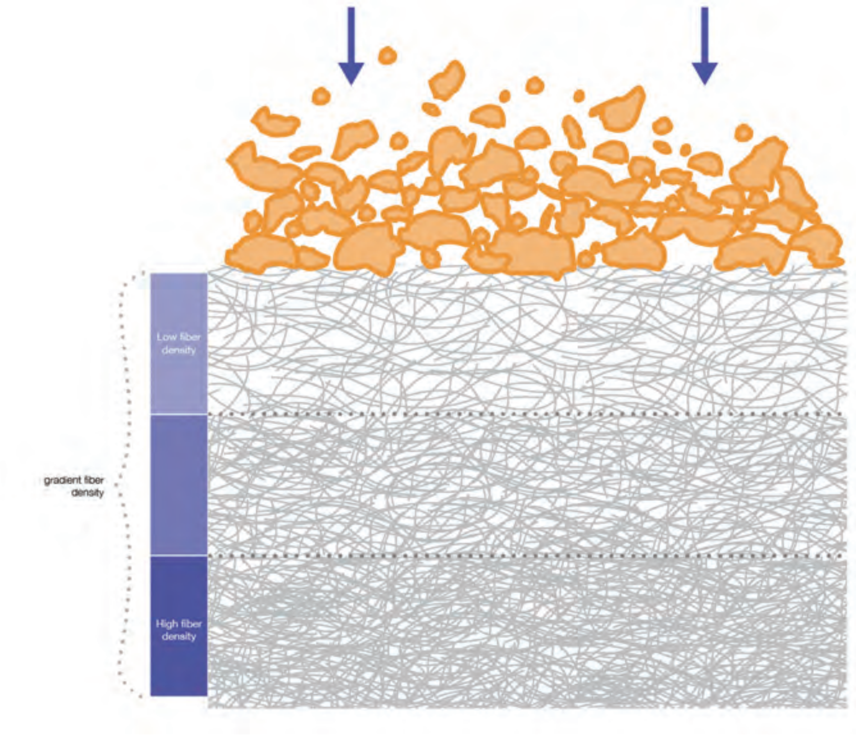


Figure 11

Illustration of cake filtration

When you consider all the methods of particle capture, it is easy to understand that a filter media with a fixed pore structure will catch particles smaller than its published absolute micron rating. Filters are not so selective that a 10-micron filter traps only 10 micron and larger particles. It will trap particles in the submicron range. For this reason, a filter will not only have one micron rating and efficiency but will have a particle removal efficiency at various micron ratings. This is reported as a particle efficiency curve or a beta rating curve, as illustrated in **Figure 12**. Absolute micron ratings, particle removal efficiency and beta ratings will be discussed in further detail in subsequent sections.

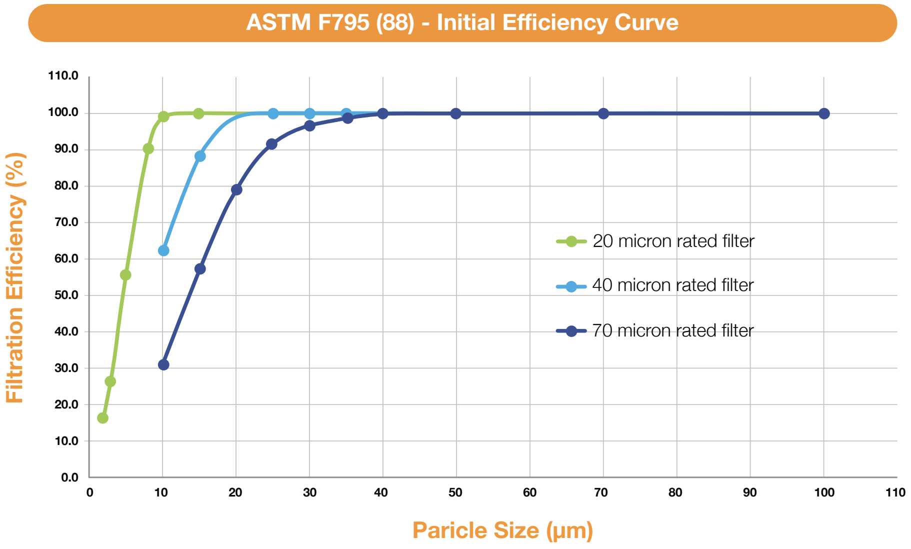


Figure 12

Particle removal efficiency curve

b. Particle Size and Shape

The physical and mechanical properties of particles play a role in filtration and are considered when selecting a filter. Physical properties such as size, morphology (shape), uniformity and whether the particle is a discrete particle or an agglomeration of particles all play a role. For example, the finer the particle, the more difficult the filtration. These small particles, which are often colloidal in nature, plug the pores of the medium increasing differential pressure rather than form a cake on the surface of the media. But if these fine particles are agglomerated, they act as a larger particle, making filtration much easier. In some cases, primarily in water filtration, coagulants and flocculants are added to aid in the formation of agglomerates.

Mechanical properties, such as hardness, play a role. A rigid, hard, non-deformable particle will be caught on the surface or within the filter media and remain in place. These particles aid in the formation of a filtration cake, which delays the building of differential pressure while retaining the contaminants, allowing for more contaminant to be caught by the filter prior to reaching terminal differential pressure. This results in high dirt holding and longer online filter life.

By comparison, a soft, deformable particle, such as a wax or gel, can change shape once it is trapped by the filter medium. A deformable particle can flatten out and cover more pores than it covered originally. These pores are no longer available for flow to trap more particles. This increases the resistance across the media building differential pressure. As differential pressure builds, in some cases, a deformable particle can be pushed through the filter medium to the point it is extruded through the clean side of the media. In this case, the filter caught and released the contaminant, reducing its efficiency. This can be combatted by using a depth media with a tortuous path to trap the deformable solids.

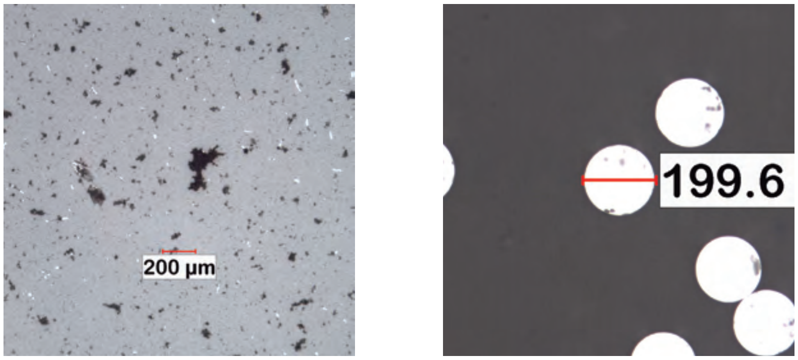


Figure 13

Comparison of spherical glass bead particles (right) to more typical non-spherical particles (left)

Particles are not mono-dimensional. They are three-dimensional, but seldom are they spherical in shape to assign one dimension to them. **Figure 13** shows examples of spherical particles – man-made glass beads – as compared to an image of particles of various types, shapes and sizes, which is more representative of the contaminant found in a process stream. Assigning a single dimension to a particle can be extremely complex so the industry simplifies the measuring process by using the concept of "equivalent spheres," as demonstrated in **Figure 14**. Particle size can be reported in many ways: (1) by length (one-dimensional), (2) by area (two-dimensional), (3) by volume (three-dimensional), and (4) other methods such as by a sphere of the same weight, a sphere of the same sedimentation rate, or a sphere that passes through the same sieve aperture. **Figure 15** illustrates these various methods. All of these are methods used for different particles and applications, and some of these methods are common in liquid cartridge filtration. Reporting the diameter of a sphere of same volume based on a particle's area is the most common method in reporting particle size in liquid cartridge filtration. The two-dimensional area is calculated by an optical particle counter or microscope, and then that area is equated to that of an equivalent sphere. The particle size can be reported as the calculated diameter of the equivalent sphere. Because there are so many methods and each method will provide a different result, it is imperative to understand what method was used to report any particle size analysis.

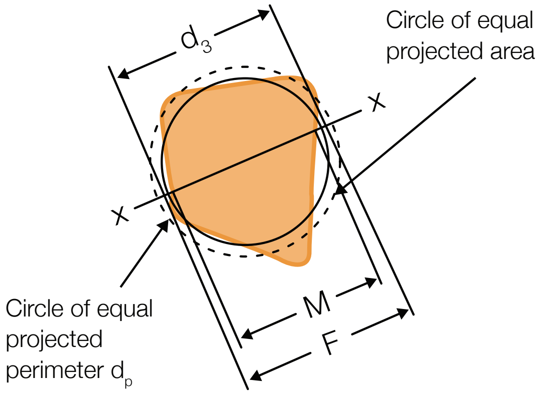


Figure 14

Illustration showing the concept of particle size by equivalent spheres based on area of particle[3]

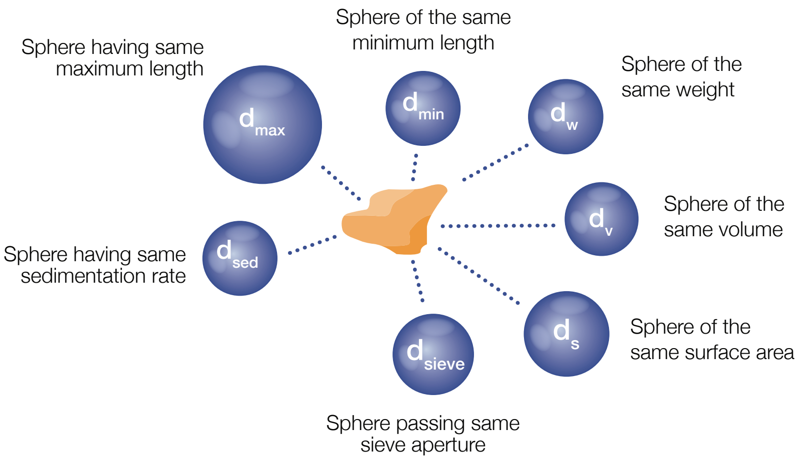


Figure 15

Illustration showing the concept of particle size by equivalent spheres using various methods[4]

Some particles can be needle-like in shape, having a significantly larger dimension in one axis as compared to the dimension in the other axis (e.g., 5 micron by 100 micron). This type of particle can pass through a pore with a size considerably less than the particle's nominal equivalent diameter.

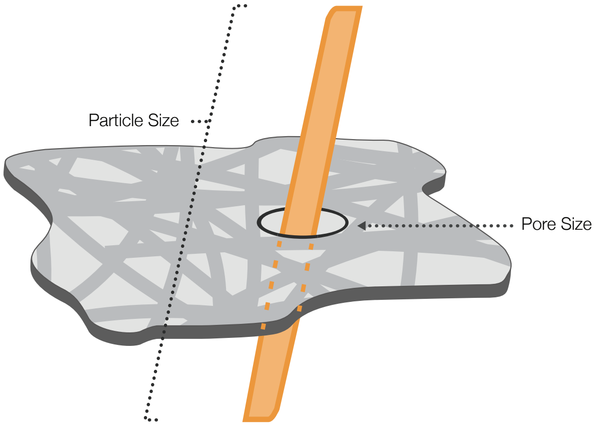


Figure 16

Exaggerated illustration of a needle-like particle passing through a pore[5]

c. Solid Contaminant Concentration

The concentration of suspended solid particles is an important factor in deciding what liquid filtration technology to select for the application. Cartridge filters are typically used for clarification of a liquid stream. The general rule of thumb on inlet concentration is 0.01% by weight or less than 100 ppmw of total suspended solids in the influent stream. This is not a firm number because it is not the only deciding factor. Sometimes cartridge filters are the only choice for various reasons. For example, economic limitations of other liquid filtration technologies, such as initial capital costs, might eliminate those technologies and make cartridge filters the technology of choice. Cartridge filters have generally low capital equipment costs as compared to other solid-liquid separation technologies. For example, it is possible other technologies might be a better fit for the project due to lower operating expenses (OPEX) when filtering process streams with a high concentration of solids, but the project is a short-term project (e.g., only months to several years) and the high initial capital cost (CAPEX) of the other technology can't be recovered over the short project timeline. In this case, it is more economical to use a cartridge filtration system.

d. Filter Micron Ratings

Generally speaking, liquid filters are rated by the diameter of the particle size they can remove. This will be discussed in further detail in subsequent sections. However, it is important to gain perspective on the size of particles cartridge filters are designed to capture. The particle size is typically in the micron range, and filters are assigned a "micron rating." A micron is a unit of measure in the metric system, and one micron is equivalent to one-thousandth of a millimeter, one-millionth of a meter and 39-millionths of an inch. There are 25,400 microns in an inch. To put this in perspective, the average cross section of a human hair is approximately 75 microns, and the smallest particle the naked eye can see is approximately 40 microns. In most cartridge filter applications, the contaminant being filtered is smaller than can be seen with the naked eye. **Figure 17** provides a perspective of common particles and their relative sizes.

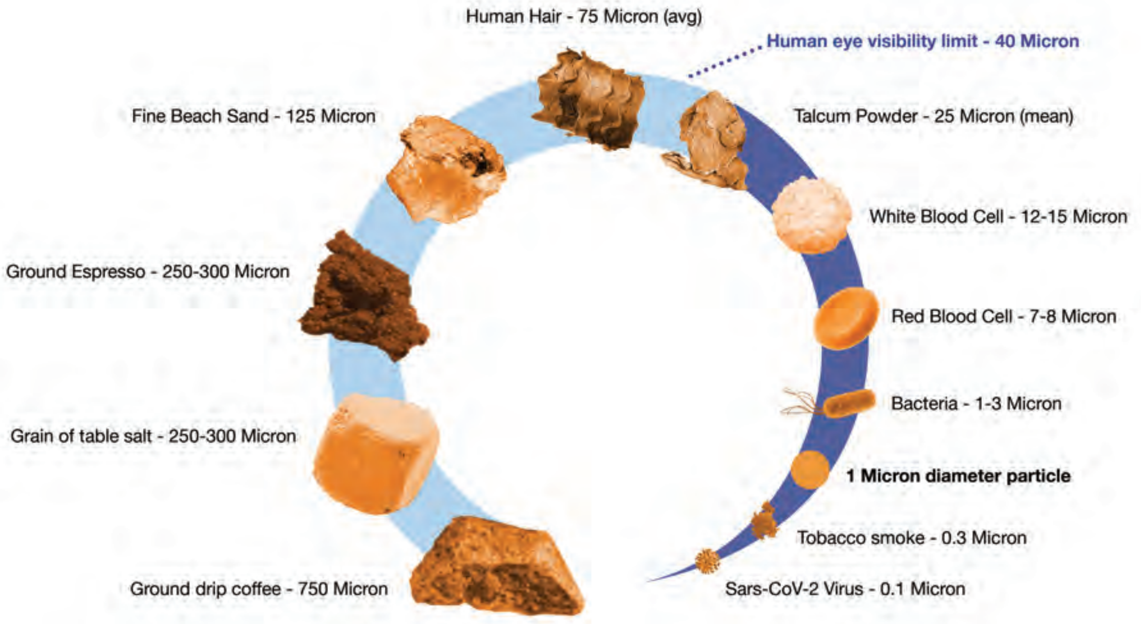


Figure 17

Sizes of common particles

The micron rating assigned to a filter indicates the size of the suspended particles the filter can remove from the fluid suspension, but it does not tell the whole story. A micron rating without the associated beta ratio or removal efficiency does not fully describe the performance of a filter.

A filter with a micron rating of 10 micron has the ability to capture some particles as small as 10-micron particles, but performance efficiency needs to be better defined or quantified, so more information is required. The most general terminology to provide performance are the terms nominal and absolute. This again still doesn't fully define performance, so it would be better to have further clarification with the filter's beta ratio or removal efficiency based on a defined test standard. There are many test standards defining performance, so it is important to know what standard is used when evaluating a filter's published performance. However, these are typically specific to an industry, and there is no generally accepted rating system, which tends to cause confusion with end users. The filtration industry principles and terminology provided in this technical report aims to equip end users with the information needed to evaluate and select the appropriate filters to meet their process goals. It is the strong opinion of FTC that ASTM F795-88 (1993) test standard should be used for rating liquid filter cartridges for use in industrial process filter applications except for specific industries such as hydraulic lubrication oils and automotive fuel filtration. These industries have their own standards specific to their processes.

e. Nominal and Absolute Ratings

There are different types of ratings assigned to filter media. The most common in increasing order of relevance and reproducibility are: 1. Nominal 2. Absolute 3. Beta.

I. Nominal Rating

A nominal rating is an arbitrary number for the performance of a filter assigned by the manufacturer. The National Fluid Power Association (NFPA) defines nominal rating as "An arbitrary micron value assigned by the filter manufacturer, based upon removal of some percentage of all particles of a given size or larger. It is rarely well defined and not reproducible." A percent performance provided with a nominally rated cartridge, if tested, is based on a gravimetric test comparing mass of upstream contaminant to downstream contaminant rather than based on a particle count and size, which is more meaningful. The lack of uniformity, reproducibility and reliability of this test method has caused it to fall out of favor in the industry.[3] Most nominal filters lack a fixed pore structure, and pore sizes can change throughout the process as a result. Some methods of manufacturing nominally rated cartridges do not allow for precise and reproducible control of the pore sizes. Therefore, the lack of reproducible, fixed pore sizes contributes to the inability to provide reproducible, measurable performance data. As a result, nominally rated cartridge filters are typically used as prefilters to reduce solids concentration and extend the life of the high-efficiency cartridge filters downstream that provide the final polishing of process fluid with more reliable and predictable performance.

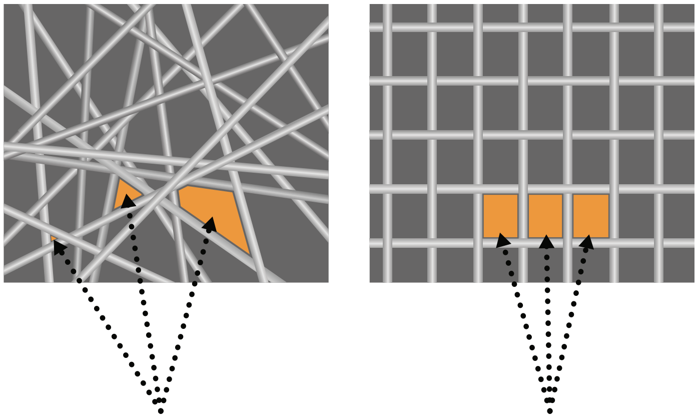
Here is a list of common nominally rated liquid filters:

- String Wound Cartridges
- Resin Bonded Depth Cartridges (most)
- Spunbonded Depth Cartridges (most)
- Meltblown Depth Cartridges (most)
- Needled Felt Bag Filters

II. Absolute Rating

According to NFPA, absolute rating is defined as "The diameter of the largest hard spherical particle that will pass through a filter under specified test conditions. It is an indication of the largest opening in the filter element." A filter is very unlikely to remove 100% of the suspended particles in a fluid stream. However, there will be a particle size "cutoff" point, or particle diameter in microns, above which no particle can pass through the filter medium. With an exact pore size consistent throughout the filter medium, this cutoff point can be defined as the absolute rating. Spherical glass beads are typically used for this challenge.

However, most media, if not all, used in absolute rated filters do not have exact and consistent pore sizes. Absolute rated cartridge filters typically utilize non-woven filter media. These are made with technologies (e.g., meltblown, spunbonded, dry laid and wet laid non-woven materials) that provide variable pore sizes, but they are produced with a consistent range of fiber diameters to deliver consistent, reproducible minimum, maximum and mean pore sizes. This level of reliable pore size distribution, fiber diameter and a fixed pore structure allows for reproducible test results when challenged with the same particle morphology and distribution. As a result, absolute rated filters can be assigned a particle removal efficiency or beta rating to further define the filter's performance.



Wide distribution of pore sizes

Uniform pore sizes

Figure 18

Non-woven (left) vs. woven filter medium (right)

Although the term absolute rating is used, it is clear this does not mean a filter will remove 100% of the suspended solids in system. But this is seldom the objective of a filter. The goal is to reduce downstream particle size and/or concentration, and absolute or beta-rated cartridge filters can achieve these goals with reasonable efficiency. The next section explains filter efficiencies and the vital role they play in attempting to predict a filter's performance. In addition, it is important to understand that filter performance data is provided based on controlled repeatable particles and particle size distributions that can be reproduced for testing in lab conditions. Most real suspensions have a wide range of particle types, shapes and distributions that can vary with process changes, therefore removal efficiency in a process may not mimic reported performance data. It should be used as a guide for filter selection but then measured in the process to make sure the goal is being achieved. Once field performance is appropriately established, it is easy to optimize performance, efficiency or life by switching to another filter grade with a different micron rating. It is important to use the same filter manufacturer when trying new filter micron ratings, a 10-micron filter from one manufacturer might have and will likely have a different filter efficiency in the process than a 10-micron filter from another manufacturer depending on the procedure employed to rate each filter. Final selection is a compromise between the amount and/or size of solid contaminant allowed through the filter, energy required to capture the solids and the economics based on the frequency of filter replacement.

Here is a list of common absolute rated liquid filters:

- Pleated Cartridge Filters (most)
- Spunbonded Depth Cartridges (some)
- Meltblown Depth Cartridges (some)
- Pleated Bag Filters (most)

f. Beta Ratio and Removal Efficiency

As mentioned earlier, not all 10-micron elements are created equally and "absolute rated" doesn't provide an end user with enough information without having a corresponding beta ratio or removal efficiency. It is important to note that this value is a designation of the removal efficiency at a given particle size and larger. Therefore, a more valuable expression of the removal efficiency of a particular filter element may be expressed as follows:

99.0% efficient at removing particles 10 micron or larger

or

$\text{Beta}_{10} = 100$

This is a more accurate representation of how this filter element should perform in a process stream and gives a comparative value to other manufacturers (subject, of course, to the manufacturer's testing protocols as well).

Percent Removal:

Percent removal is calculated via the following formula:

$$\%\ \text{Removal Efficiency} = \frac{\#\ \text{Particles at X Micron and Greater}_{\text{Inlet}} - \#\ \text{Particles at X Micron and Greater}_{\text{Outlet}}}{\#\ \text{Particles at X Micron and Greater}_{\text{Inlet}}} \times 100$$

X = micron rating being evaluated

Therefore, we can easily calculate our efficiency where we count 100,000 particles upstream and 1,000 particles downstream:

$$\%\ \text{Removal Efficiency} = \frac{(100{,}000 - 1{,}000)}{100{,}000} \times 100$$

$$\%\ \text{Removal Efficiency} = 99.0\%$$

Beta Value:

A beta value is simply a ratio of particles upstream and downstream:

$$\beta_x = \frac{\#\text{ Particles at X Micron and Greater}_{\text{Inlet}}}{\#\text{ Particles at X Micron and Greater}_{\text{Outlet}}}$$

X = micron rating being evaluated

Therefore, we can also calculate our beta value where we count 100,000 particles upstream and 1,000 particles downstream:

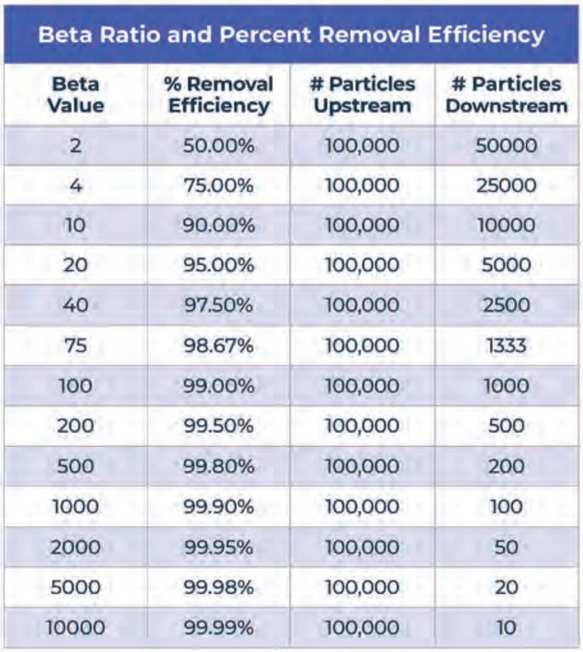
$$\beta_x = \frac{100{,}000}{1{,}000}$$

$$\beta_x = 100$$

Using the following formula, one can convert from a beta rating to percent removal efficiency:

$$\%\text{ Removal Efficiency} = \frac{\beta - 1}{\beta} \times 100$$

It would appear that both values give us an accurate snapshot of the performance of our filter, and it would seem that there would be little difference in expressing the performance one way or the other. While this may be true, it can be demonstrated that expressing efficiency in a beta value is more precise in demonstrating filter performance. Consider the table below, which shows beta values and equivalent percent removal.



Beta Ratio and Percent Removal Efficiency

Beta Value	% Removal Efficiency	# Particles Upstream	# Particles Downstream
2	50.00%	100,000	50000
4	75.00%	100,000	25000
10	90.00%	100,000	10000
20	95.00%	100,000	5000
40	97.50%	100,000	2500
75	98.67%	100,000	1333
100	99.00%	100,000	1000
200	99.50%	100,000	500
500	99.80%	100,000	200
1000	99.90%	100,000	100
2000	99.95%	100,000	50
5000	99.98%	100,000	20
10000	99.99%	100,000	10

Table 1

Comparison of beta ratio and particle removal efficiency

One might assume that there is not a significant difference between 99% and 99.9% removal efficiencies. However, based on the table above, if we have 100,000 particles coming into the filter, there is a significant difference of 900 particles between the two efficiencies (1,000 vs. 100 particles counted downstream).

Keeping in mind that this sample is only a snapshot in time and may only be a 100 mL sample size, if we are evaluating a system of 100 gallons per minute, that is the equivalent of 378,541 mL per minute. Considering there is a difference of 900 particles between the two efficiencies and expanding our 100 mL sample to the daily volumetric throughput the filter will handle, the performance difference between 99% and 99.9% efficiency is significant. The 99% filter will allow 490,589,136,000 more particles to pass daily than the 99.9% efficient filter.

This value assumes consistent inlet quality and does not factor in changes in filter performance due to cake formation. However, it does demonstrate the significant difference in initial efficiencies between a filter rated at 99% and another filter rated at 99.9%, which the rated value does not clearly imply. The beta value gives us a more granular comparison between the two (beta 100 vs. beta 1,000), and it implies the significant difference in performance that could otherwise be overlooked.

Beta ratio or particle removal efficiency are absolutely necessary to clearly report filtration performance. And these must be based on defined conditions as provided by a test standard, ideally the standard accepted by that industry. There are several standards used, and most are borrowed from other industries and misapplied to industrial filtration. A short list of common test standards is provided below, along with the appropriate industry for that standard. In general industrial filtration, FTC recommends ASTM F795-88 (1993) Standard Practice for Determining the Performance of a Filter Medium Employing a Single-Pass, Constant-Rate, Liquid Test.

Below is a short list of test standards by industry.

- ▶ General Industrial Filtration: ASTM F795-88 (1993): Standard Practice for Determining the Performance of a Filter Medium Employing a Single-Pass, Constant-Rate, Liquid Test
    - Single-pass filtration test recommended for General Industrial Cartridge Filtration
- ▶ Hydraulic Fluid Power: ISO 16889:2008: Hydraulic fluid power – Filters – Multi-pass method for evaluating filtration performance of a filter element
    - Multi-pass filtration test recommended for filtration of hydraulic fluids
- ▶ Diesel Fuel for Combustion Engines: ISO 19438:2003: Diesel fuel and petrol filters for internal combustion engines – Filtration efficiency using particle counting and contaminant retention capacity
    - Multi-pass filtration test recommended for filtration of diesel fuel and petrol filters for internal combustion engines

g. Pleated vs. Depth

Filtration medium can be categorized into two main categories: pleated and depth.

Depth filters typically have a greater media thickness than pleated filters. They can also be made with a gradient density, meaning the pore size on the inlet is greater than the pore size on the final layer of media. The pore sizes gradually get tighter from the inlet side to the outlet side. Depth cartridges use the principle of depth filtration, described earlier, where the particles are trapped within the depth of the filter medium. They can be made as cylindrical cartridges in the shape of tubes, as multilayered inside to outside flow bag filters, or cartridges can be pleated with multiple layers of media creating depth.

Depth filter cartridges are typically nominally rated but are also available by some manufactures in absolute ratings, although less common. They are most commonly used in applications with deformable solids or to filter gels. The tortuous path provided by the fibers and depth in the filter media can trap deformable solids if the differential pressure of the filter does not exceed the point of extrusion. They typically utilize large fiber diameters than those in pleated cartridges and have larger pore sizes. So, the primary mechanism of particle removal is through depth straining, as they rely on the depth for particle entrapment rather than a smaller pore size used in surface straining. Depth filters typically have lower dirt holding capacity than pleated cartridges, as they have little surface area and higher face velocities, which eliminate cake formation to provide solids loading from caking.

Figure 19

Side view of meltblown depth cartridge

By comparison, pleated filters rely on the finer fixed fiber pore structure and more surface area for filtration primarily by the surface straining to provide published micron ratings and efficiency. The reason for pleating is to maximize the effective media surface area, which reduces the flux rate across the media. The impact is a lower face velocity, which provides less drag force on the particles and reduces the resistance across the media. The reduced drag forces reduce compression of the particles, which then allows for cake formation and ultimately reduces compressibility to maximize cake thickness. So, although surface straining is the primary mechanism of particle entrapment in a pleated filter media/cartridge, caking also plays a significant role. For this reason, pleated filter cartridges typically have dirt holding capacities that are much higher than their depth counterparts.

Depth straining also plays a role in particle entrapment in pleated cartridges but to a much lesser extent than depth filters. However, pleated cartridges can be manufactured with multiple layers of filtration media to create a pleated depth media to increase the impact of depth straining, when appropriate, but not to the extent of depth achieved in a depth filter. This can be applied in applications with a mix of rigid and deformable solids where lower flux rate and lower differential pressures, along with depth to increase entrapment of deformable particles, is necessary.

Figure 20

Side view of pleated cartridge filter

Pleated filters utilize filtration media made from various technologies, such as meltblown synthetic, dry or wet-laid cellulose and glass fiber media, among other materials. These technologies allow for manufacturers to provide consistent pore structures made with very fine fiber diameters (<1 micron to 10 micron and larger), which provide higher porosity or void space within the filter media with controlled basis weight or mass of fibers added. The fibers and tight control of pore size and distributions allow for reliable micron and efficiency ratings, as well as low pressure loss from high porosity and lower flux rates from pleating. As a result, most pleated filter elements have an absolute micron rating with a beta and removal efficiency rating.

h. Fluid, Particle, and Slurry Properties – Importance and Impact

When designing a filtration system for a fluid process stream, one must consider properties of the fluid slurry as a whole and not just the properties of the liquid and the solids. Temperature, pressure, aging effects and upstream processes all effect the properties of the slurry are to be considered when designing a filtration system, but the system flow rate is the single most important factor to consider. Fluid viscosity is the most important property of the liquid, but chemical composition, density, dissolved solids, pH, volatility, corrosiveness and toxicity should all be considered as well. The particle size and concentration are the two most important properties of the solids to consider, while not overlooking chemical composition, density, charge, shape, flocculation, strength, abrasiveness, hardness/deformability, and uniformity.[2]

After carefully evaluating the properties of the process stream, a proper filtration system can be designed. But in order to maximize the throughput through a filter cartridge to achieve maximum filter life, defined as volume of fluid processed prior to reaching the filter's terminal differential pressure, the cartridge filter design properties and the properties of the fluid stream need to be considered. The key factors that affect the life of a cartridge filter are outlined below.

Properties of the Fluid Stream

- Flow Rate
- Liquid Viscosity
- Hardness of Solids (e.g., rigid, deformable)

Properties of Filter Cartridge (cartridge and media)

- Effective Media Surface Area
- Media Flux Rate
- Media Porosity and Thickness
- Permeability (media)
- Pore Structure (fixed or non-fixed)
- Terminal Pressure Drop

All these factors affect cartridge filter life. Fortunately, in a typical plant operation, most of these variables are fixed. Therefore, if the goal is to increase fluid throughput or filter life, two variables that can be adjusted to extend filter life and volume of fluid processed prior to reaching terminal differential pressure are effective filter media surface area and filter media flux rate. With respect to increasing fluid throughput or filter life, the effective media surface area presents the biggest area of opportunity for filtration technology to have the most significant impact on a plant's operations. As a general rule of thumb, filtration systems should be designed with a media flux rate of 0.5 gpm/ft2 or less for fluids with water-like properties. This flux rate should be adjusted for lower- and higher-viscosity fluids, but it serves as a great starting point.

i. Pressure Drop – Clean, Differential, and Terminal

Terminal differential pressure, or recommended differential pressure for changeout, across the media has been discussed in previous sections. It is assigned by the filter element manufacturer, and it is the differential pressure across the filter at which the manufacturer recommends replacing the filter elements. This differential pressure is selected for more than one reason, but the primary reason is this is the point where most of the filter media is spent, and the filter has reached its capacity of loading solid contaminant without the risk of pressure drop building too rapidly to the point the filter exceeds its maximum differential pressure rating, resulting in the filter failing and releasing the trapped solids downstream. The maximum differential pressure rating is also assigned by the manufacturer, and it is the maximum differential pressure the filter can handle structurally without the risk of mechanical failure. Notably, these are typically at stated standard operating temperatures and with non-corrosive fluids. These ratings can and should be adjusted for the application based on the chemical and thermal conditions of the process fluid.

A common design criteria of a filtration system is the clean pressure drop. With little exception, all customers require this information when evaluating a filtration system. It is also an important parameter considered by the manufacturer on the design side. For end users, this is critical because they must anticipate the pressure loss in their systems caused by the equipment. There is pressure loss throughout their entire process (e.g., every pipe run, pipe bends, every change of section, through every piece of equipment). A pump cannot be specified without an estimate of pressure loss that the process equipment will contribute. Also, any changes to equipment once installed can derail achieving the intended production rates.

It is important for end users to start off with a low clean differential pressure as it minimizes system energy usage and allows for a given filter to have extended life until terminal differential pressure is reached. However, most users tend to assume that, between any two filters, the one offering a lower clean differential pressure will last longer. This is often not the case because differential pressure rise depends on the solids loading mechanism which is inherently tied to the filter media technology and configuration. For example, some loading mechanisms result in cake formation while some don't. As a result, in order to make an informed choice among several filter element options, it would be very important for end users to consider not only the clean pressure drop but also the media technology, element configuration, effective surface area and solids loading profile data under standard test conditions.

There are several governing principles that allow the pressure loss across a filtration system to be calculated, specifically Bernoulli's Principle and Darcy's law.

Bernoulli's principle can be applied to changes of section within a filtration system (e.g., inlet and outlet nozzles) to calculate anticipated pressure losses.

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

where:

P = static pressure of the fluid across at the cross section

ρ = density of the flowing fluid

g = acceleration due to gravity

V = mean velocity of the fluid at the cross section

h = elevation at the center of the cross section with respect to datum

The clean pressure drop across the filter element is affected by a number of factors, including filter surface area, viscosity of the solution and filter medium thickness and permeability, as per Darcy's law.

$$Q = \frac{k\,A\,\Delta P}{\mu\,L}$$

where:

Q = volumetric flow rate

k = media permeability

A = filter surface area

ΔP = pressure drop (P_{inlet} - P_{outlet})

L = thickness of the media

μ = viscosity of the continuous phase

$$\Delta P = \frac{Q\,\mu\,L}{k\,A}$$

The equation can be solved for pressure drop as shown above. The flow rate and viscosity are properties of the fluid and are determined by the process conditions. But, the media permeability, media thickness and filter media surface area are properties of the filter/filtration system. The dry media thickness is typically fixed by the medium required to meet the filter micron rating and efficiency. It is apparent that if the filter surface area can be increased, it can significantly reduce the pressure drop across the media. The biggest impact we can have on reducing pressure loss is by increasing filter effective surface area. The benefit of surface area stands out even more when cake formation occurs. Darcy's equation can be applied to both the filtration media and the filter cake, which is known as the two-resistance model. Increasing the surface area not only increases the available media surface for filtration but also increase the area available for the filter media caking. How increased area impacts cake formation and cake thickness impacting the filter dirt holding – filter life – is significant and is described in the next section.

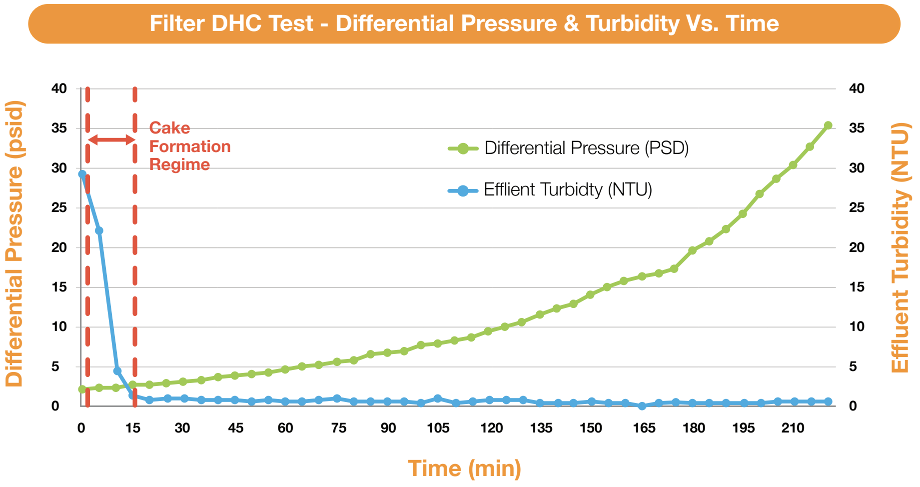


Figure 21

Typical differential pressure curve (hockey stick shape)

Figure 21 provides a typical differential pressure curve seen in liquid cartridge filtration under constant flow conditions. There are several aspects of this graph to notice. First, look at the differential pressure curve (green). This curve plots the filter's differential pressure over time. The shape of the curve is exponential like the shape of a hockey stick. The cause is seldom considered or explained. The details of the phenomenon are complex but fairly easy to explain. And, considering the impact permeability has on pressure loss from Darcy's law, it makes much more sense. Initially, upon start-up, the media is clean and free of the solid contaminant, so the permeability of the media is established based on the media properties and porosity (e.g., 60% open volume). As solids are introduced and captured by the media, this pore volume gets plugged (see **Figure 22**, second illustration from left). The impact on the differential pressure is fairly low, so the ΔP curve is linear with a very slight increasing slope. As more contaminant plugs the pores, the impact becomes more significant because the media porosity decreases but the flow is constant (see **Figure 22**, second illustration from right). All other variables in Darcy's equation remain the same, but with pores plugged and the same flow and same concentration of solids, the fewer remaining pores start to plug more rapidly. As a result, the slope of the curve becomes greater. While the solids are being trapped by the media, cake formation also occurs. At this point, the two-resistance model comes into play. The particle capture efficiency and outlet fluid quality (blue curve) improves as cake formation occurs. This also impacts the differential pressure. The cake that forms continues to trap more particulate under the same flow and concentration. Cake formation is beneficial as it increases the dirt holding and filter life, and it takes over as the dominant changing resistance impacting differential pressure. It increases available porosity and traps more particles. The other factor that adds to the complexity is filter cakes can be compressible or incompressible. The cakes in industrial filtration are, more often than not, compressible. So, as differential pressure builds, the cake can compress, reducing the permeability of the cake. So, at the same constant rate, there are several increasing resistances: a filter medium and cake that are filtering more particulate and a cake that is compressing. The impact on the differential pressure curve is clear. The slope of the curve will increase, becoming a much steeper curve almost to the point it is vertical. Toward the end of the life of the filter, the steepness of this increasing slope is the reason filters have a terminal differential pressure lower than their failure differential pressure. The rate of change of differential pressure is so rapid that the filter can potentially reach failure differential before an operator can schedule changing out the filters. The operators need advanced notice to isolate the housings and divert flow before catastrophic failure occurs. Therefore, it is not advisable to operate above the manufacturer's recommended differential pressure.

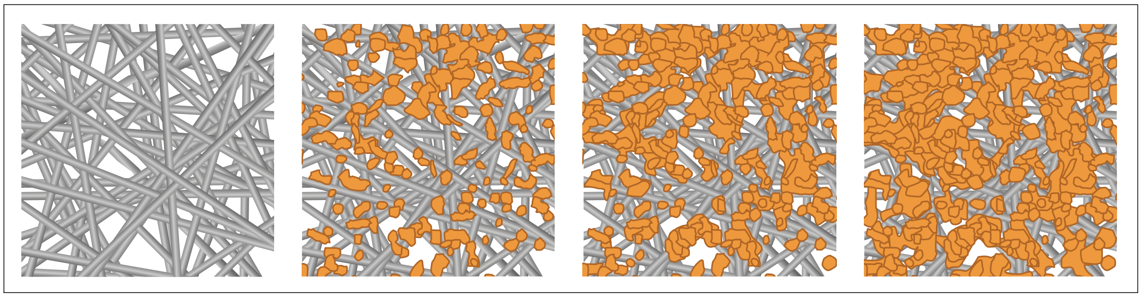


Figure 22

Illustration of particle entrapment and cake formation to demonstrate how efficiency can increase over time

j. Surface Area in Relation to Cartridge Filter Performance

It is well documented that surface area plays a crucial role in the solids loading capacity or "online life" of a filter cartridge. Widely applied filtration theories, such as Darcy's law described previously, and the Kozeny–Carman equation directly tie the increase in surface area to a reduced differential pressure.

As contaminants build along the filter media, differential pressure builds. A filter's online life is therefore affected directly by both the effective surface area, which determines how much area over which the contaminants can build, and the flux rate, which determines the velocity at which particles impact the defined surface area. The flux rate (flow rate per unit area) influences the cake loading mechanism of contaminants on the filter surface and also the pressure loss across the media and filter cake. Reducing the flux rate reduces the rate at which the differential pressure across the filter builds and, in turn, translates to increased fluid throughput, higher filter solids loading capacity and longer online life. This can be expressed as throughput or dirt holding capacity.

Throughput (T), the volume of fluid (e.g., gallons) a filter can process prior to reaching terminal differential pressure, is related to the surface area and flux rate as per the following equation:[5]

$$T_1 = T_2 \left(\frac{A_1}{A_2} \right)^n$$

where:

T_2 = throughput original

T_1 = throughput extended

A_2 = original effective filter surface area

A_1 = expanded effective filter surface area

n = factor between 1 and 2, influenced by cake loading profile due to the contaminant physical properties

As the equation shows, fluid throughput can be as much as the square of the increase in surface area. For example, if surface area is doubled, throughput can potentially be increased by four times. In the worst-case scenario, doubling the surface area will result in twice the throughput. All applications vary as a result of the properties of the fluid and solids, but in almost every case, increasing surface area has a greater impact on throughput as long as the surface area is effective surface area. There are a few minor exceptions in the case of solids that build a large filter cake that exceeds beyond the void space available in the filter for cake formation. Other limitations can contribute toward making the surface area ineffective. These include limited filter void space (high pleat counts), improper media supports, media buckling (very high flux), and fluid dynamics within the filter housing. The impact of increasing the surface area is demonstrated in the figures below. **Figure 23** and **Figure 24** demonstrate how filter life and throughput can be increased by demonstrating the impact the lower flux rate has on the filter caking. The ability of the filter to increase caking on the additional surface area and to increase its cake thickness (double in this case) shows how doubling the surface area can result in four times the filter life.

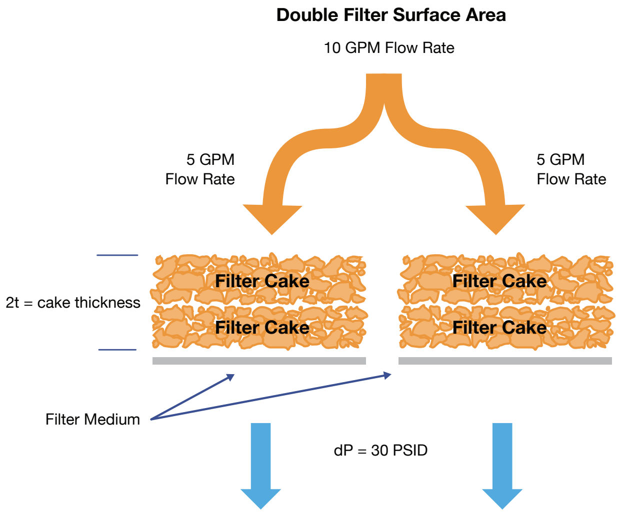


Figure 23

Illustration of how double the surface area can result in four times the filter life/dirt holding capacity

Following the dynamics within the media and the cake, this can be further explained mathematically with a derivation of Darcy's law.

As previously mentioned, Darcy's law states:

$$Q = \frac{k\,A\,\Delta P}{\mu\,L}$$

where:

Q = volumetric flow rate

k = media permeability

A = filter surface area

ΔP = pressure drop (P_{inlet} - P_{outlet})

L = thickness of the media

μ = viscosity of the continuous phase

Including the cake that forms on the media, the equation at terminal differential pressure may be rewritten as:

$$\frac{Q}{A'} = \text{Flux} = \frac{K_{overall} * \Delta P_f}{\mu * (L_c + L_m)}$$

where:

A’ = surface area available for flow through the cake (usually same as A, unless cake thickness is significant)

$K_{overall}$ = combined permeability of media and cake

ΔP_f= final or terminal pressure drop

L_C = thickness of cake

L_m = thickness of media

$$\text{Cake Volume} = L_C * A' = V * K_C$$

where:

V = throughput (or volume of fluid passed through the filter)

K_C = cake-specific characteristic constant

L_C can be interpreted as:

$$L_C = \frac{V * K_C}{A'}$$

As far as media is concerned, the available pore volume >= volume of particles captured.

$$A \times L_m * \varepsilon \geq V * C_p * \eta$$

where:

ε = porosity of the media

C_p = concentration of particles in the incoming slurry (mass per unit volume)

η = media efficiency for particle capture

At terminal ΔP, the media thickness is represented as a minimum, L_m(min) that could afford the throughput. Accordingly:

$$L_m\,(\text{min}) = \frac{C_p * \eta * V}{\varepsilon_f * A'} = \frac{K_m * V}{A'}$$

where:

ε_f=final porosity of media at terminal ΔP

K_m = media-specific characteristic constant

Substituting for L_c and L_m, Darcy’s law for the combined media and cake may be written as:

$$\frac{Q}{A'} = \frac{K_{overall} * \Delta P_f * A'}{(K_C + K_m) * \mu * V} = \frac{K' * \Delta P_f * A'}{\mu * V}$$

This equation explains the relationship between Throughput (V) and A' (surface area):

$$V \propto A'^2$$

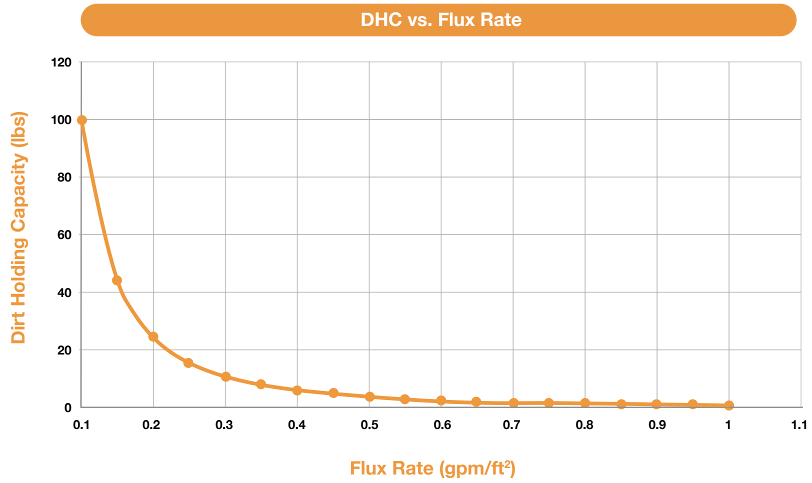


Figure 24

Relationship between dirt holding capacity (filter life) and flux rate

Now that we have established that surface area is a critical property, we must understand that surface area must be optimized for each cartridge. Simply packing in as much surface area as possible doesn't always lead to improved performance. It has its limits, which are cartridge specific. There is a balance between surface area and void space in the cartridge. Optimal surface area in a cartridge is critical to its performance and to maximizing economics. Without optimization, the cartridge filter surface area can be inadequate or excessive. **Figure 25** demonstrates the impact of inadequate, excessive, and optimal surface area on dirt holding performance. Improper or non-optimal filter design or application can contribute toward making the surface area ineffective. These include limited filter void space (high pleat counts), improper media supports, media buckling (very high flux), and fluid dynamics within the filter housing.

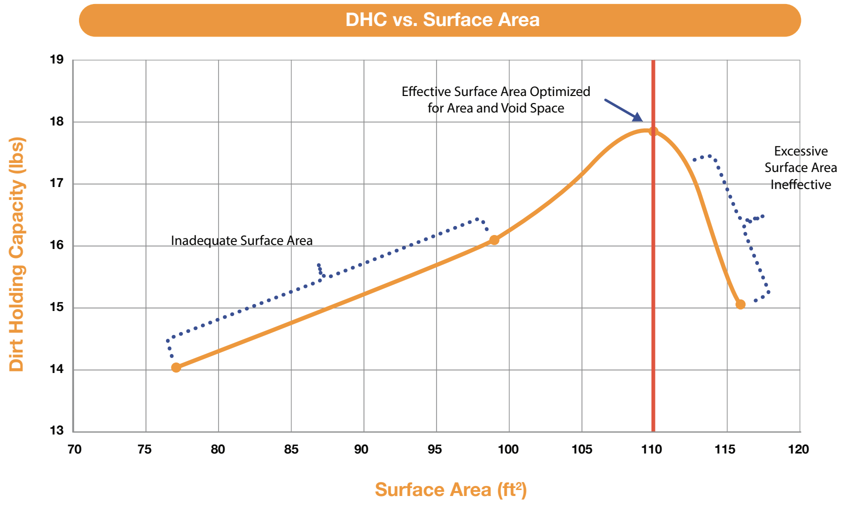


Figure 25

Relationship between dirt holding capacity (filter life), effective surface area, and void space limit

k. Impact of Surface Area on Overall OPEX and CAPEX

Overall expenditure towards filter usage, not including the one-time cost of the filter vessel, includes:

- Total annual direct filter cartridge cost (= total changeouts x cost per changeout)
- Labor cost
- Other consumable cost per changeout (e.g., fluid losses and vessel seals, among others)
- Filter disposal cost upon each changeout
- Cost of shipping and storing filters
- Operator hazard-related costs
- The cost of plant downtime or equipment replacement if the right filtration technology is not deployed

By way of routine maintenance, cartridge filters need to be changed out once they reach a defined terminal differential pressure. In doing so, the captured particulates are effectively removed from the system, thereby ensuring the longevity and performance of other expensive process equipment, while also avoiding secondary problems associated with the continued presence of the contaminants.

Longer duration between filter changeouts is directly related to savings on annual filter cost. The total cost of filtration and operation can be reduced significantly through the use of filters optimized for both efficiency and longer online life between changeouts, which provides direct and indirect cost savings. However, it may be reiterated that filters need to be changed out as soon as terminal differential pressure is reached. Potentially, some of the damage caused to downstream equipment due to passage of contaminants could be irreversible.

The significance of the economic impact of a higher effective surface area filtration system is demonstrated in the table below. This table evaluates a scenario where effective surface area in a filter vessel is doubled. This can be done by replacing existing filters with higher surface area filters, or by replacing the vessel with one that provides twice the surface area. According to the previous exercise on throughput, we can expect two-to-four times additional filter life. This can also be viewed as two-to-four times more dirt holding capacity or two-to-four times more throughput. They are all directly connected, so the impact is the same on all. We evaluate the impact if the throughput is tripled or quadrupled. It also considers the new filters being purchased at a higher cost, specifically 25% and 50% more in cost. The operational savings is provided as a percent savings on direct consumable costs. This does not take into consideration the indirect savings for other factors mentioned previously, such as labor. It is clear the impact is significant with a 25% to 69% direct savings and cannot be overlooked. The data has been normalized for demonstration purposes.

Surface Area	Filter Life (days)	Cost per FIlter ($)	Filtration Cost per Day ($)	Savings (%)
1	1	$1.00	$1.00	
2	4	$1.25	$1.31	69%
2	4	$1.50	$1.38	63%
2	3	$1.25	$1.42	58%
2	3	$1.50	$1.50	50%
2	2	$1.25	$1.63	38%
2	2	$1.50	$1.75	25%

Table 2

Normalized chart providing scenarios of OPEX impact of doubling the surface area

5. Filtration System Sizing and Design

Characteristics of the liquid process stream will greatly affect the design and operation of a liquid-solids cartridge filter. The following factors must be determined before designing the filtration system:

- Fluid composition of liquid phase
- Flow rate – operating, minimum, and maximum design
- Temperature – operating, minimum, and maximum design
- System pressure – operating, minimum, and maximum design
- Viscosity of inlet slurry at operating conditions
- Density of inlet slurry at operating conditions
- Inlet concentration of solid particles at operating conditions
- Particle size distribution of solid particles at operating conditions
- General idea of type of solid contaminants (e.g., mechanical and physical properties)
- Allowable pressure drop/loss – clean and dirty
- Effluent quality removal requirements (i.e., desired maximum solid concentration or particle size in effluent)
- Footprint available and vessel orientation
- Vessel materials of construction and Non-destructive Examination (NDE) requirements

a. Proper System Design

With this information, FTC's experienced application engineers can properly design a liquid-solids filtration system with reliable and predictable performance for process reliability.

A properly designed liquid-solids filtration system must satisfy several criteria for good operation.

- Designed to minimize clean pressure drop
- Designed with proper materials of construction for chemical and thermal compatibility
- Designed with filter element micron rating and efficiency based on the industry's accepted test method
- Provide desired effluent fluid quality while maximizing online life
- Designed to maximize effective filter media surface area in the smallest footprint
- Designed to provide the best balance of capital expenses (CAPEX) and operating expenses (OPEX)
- Have appropriate ports, port locations and instrumentation to aid operations in the ability to effectively operate the equipment (e.g., differential pressure gauges)
- Allow for variation in the process flow rates and solid contaminant loading (within reason) without adversely affecting removal efficiency
- Designed with consideration of operator's ability to safely operate the equipment by maximizing ergonomics and minimizing hazards

b. Common Liquid Filtration Equipment Issues

The single most common issue with liquid-solids filtration equipment in service today is undersized equipment. Project engineers are not necessarily at fault when working to meet specified goals or when trusting a vendor that claims its equipment can meet company design criteria. Unfortunately, corporate departmentalization has created a continuous focus on CAPEX and not enough emphasis on the OPEX impact of under-designed or improper process equipment. Sadly, key parameters that can protect the client from this situation are left out of project specifications (e.g., lack of filtration test standards) or, at times, some vendors will make performance claims they cannot meet or go unchecked. These issues are oftentimes addressed later by operations once a facility or new process unit is up and running.

Another common cause involves replacing equipment in-kind or copying equipment specifications from an existing plant and applying them to new facilities. While this can work if the plant design has been optimized and liquid filtration performance is meeting design criteria, often the same underperforming filtration system placed at the original facility is duplicated at the company's other facilities. In some cases, the plant has resolved their issues by replacing the original specified underperforming cartridge with an optimized alternative filter, but then the project team replaces the filter with another low-capital-cost piece of equipment from the same vendor with a different element configuration, and the optimization process at the operations stage has to start all over again.

The examples are almost endless, but another widespread problem involves well-designed vessels paired with inefficient element or elements that do not have a necessary elastomeric seal to avoid particle bypass. In this case, low-cost elements often mask critical inefficiencies that show up later in the form of costly issues downstream that go unnoticed until it is too late. For example, a catalyst reactor bed will not show higher differential from fouling initially after a low-efficiency element is installed upstream. The bed fouling will not show up until much later, and it may be too late at that point. When considering the cost impact of catalyst replacement or the loss of production due to unplanned shutdown, the cost of reliable liquid filter elements with predictable performance is insignificant.

Finally, filter element and media chemical and thermal compatibility can often be overlooked. It is not uncommon for a plant to be using a filter with incompatible materials. This can lead not only to inefficient filtration, but also to catastrophic failure of the filters, with solid contaminant and filter materials ending up fouling downstream equipment. In addition, filter elements made from incompatible material can leach or release into the stream assembly, lowering the surface tension of the process stream and resulting in foaming within the process unit.

c. Advancements in Cartridge Filtration Technology

Although cartridge filters have been used in fluid processing for many years, the industrial end users are constantly focused on process reliability and improved process efficiencies. As a result, they demand more reliable filtration performance, higher flow capacity, lower clean pressure drop, longer online filter life, smaller footprint, lower energy demand, minimal operator exposure to hazardous fluids and the reduction of waste.

Cartridge filters are one of the most common forms of liquid-solids filtration technologies used in fluid processing to mitigate unwanted solid contamination. Even though pleated cartridge filters have been used in process systems for many decades, cartridge technology is continually evolving to adapt to the ever-changing needs of the industrial fluid processing industry. However, most of the advances in recent years have been in media technology or pleat configuration.

Thanks to innovation in pleating technology, pleat configurations such as radial pleats, curved pleats, “W” shaped pleats and FTC’s Platinum® serpentine pleat have had an impact on advancing cartridge filtration. In addition, manufacturers have learned the benefit of co-pleating multiple layers of media and using pleat spacers to improve filtration dirt holding capacity and filter life.

Most of the more recent innovation has come from advancements in filter media manufacturing technology. These advancements have resulted in a large offering of media with beneficial features such as finer fiber diameters, higher media porosity and greater gradient density. These can all contribute to important benefits, such as lower pressure loss, higher dirt holding capacity, reduced particle capture size and improved efficiencies. Further advancements, such as media made from specialty polymers, have broadened the applications for which cartridge filters can be provided as a solution to solids contamination due to the increased chemical and thermal compatibility these materials provide.

The fiber and media manufacturers have done their part in advancing technology. However, the filter manufactures have been slower to bring groundbreaking technologies to the industrial fluid process market. Industrial fluid process cartridge filter suppliers might introduce a truly game-changing cartridge design once per decade. Since the late-1980s and early-1990s, some unique cartridge designs have been developed, and these have all made their impact on the market. Still, there is one thing all these technologies have had in common: They have all been developed with a cylindrical cartridge shape in mind. Other fluid process markets (e.g., air filtration) have used other shapes, but industrial liquid filtration has been stuck on the same cylindrical shape since its inception.

Recent advancements have brought a new shape to the industry. In 2019, FTC launched its Invicta® technology: a novel trapezoidal filter cartridge used in traditional cylindrical filter vessels. The impacts a coreless, trapezoidal filter cartridge has on filtration performance, flow capacity, clean pressure drop, filter life, equipment footprint and waste reduction are significant. This unique trapezoidal shape eliminates unused dead space in the filter vessel with better filter packing density. The filter packaging density is demonstrated in **Figure 26**. In addition, each filter has ideal media packing density with significant surface area. Collectively, the results are as much as a 176% increase in effective filtration media surface in a given footprint as compared to conventional cartridge filters. **Figure 27** provides the impact on surface area between Invicta® cartridges and traditional conventional cylindrical cartridges. As demonstrated previously, the CAPEX and OPEX benefits are overwhelmingly advantageous to process operations.

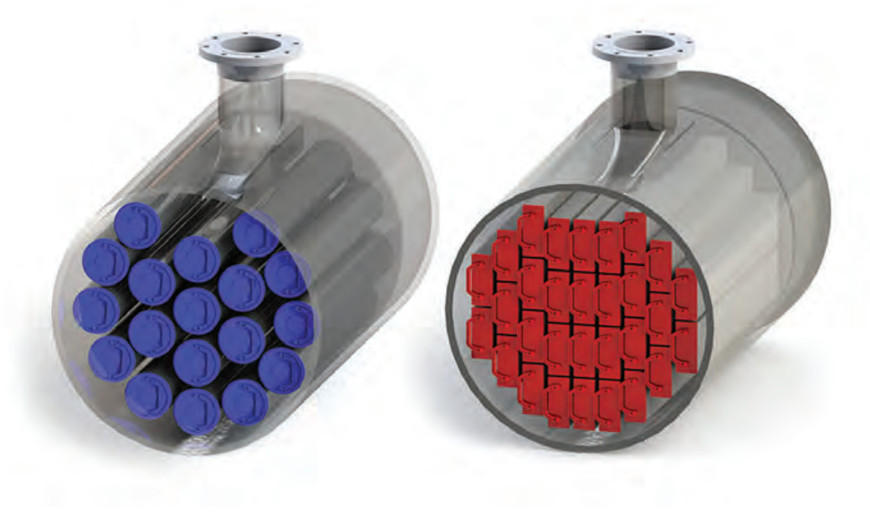


Figure 26

Comparison of a 36" diameter filtration housing with traditional 740-style cartridges (left) as compared to trapezoidal-shaped Invicta® cartridges (right)

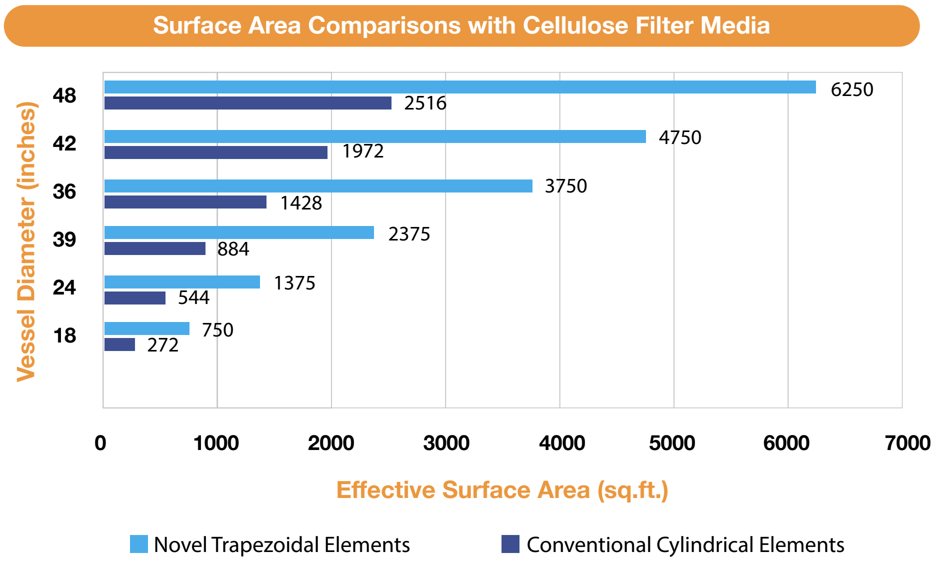


Figure 27

Surface area comparison of trapezoid-shaped Invicta® cartridges with cellulose media in varied housing diameters as compared to traditional 740-style cartridges

6. Conclusion

As is true with any filtration process, whether liquid-solids, liquid-liquid, gas-liquid or gas-solid, filtration is important to protect performance, quality and safety; to remove unwanted components and contaminants; and to ensure the desired outcome. This report focused solely on liquid-solids industrial cartridge filtration technology for processing liquids. As proven, the choice of technology for the separation is crucial for the success of the process. So, too, are a number of critical factors, including (i) understanding micron rating and efficiency, and specifying an efficiency tied to a micron rating based on a test standard recommended to be ASTM F795-88(1993); (ii) managing a lower flux rate to maximize filter life, ideally 0.5 gpm/ft^2 or less for water; (iii) the manufacturer's understanding of slurry, fluid and particle properties, and all process conditions in order to provide a properly sized vessel; (iv) avoiding low-cost filters with inefficient media and/or sealing surfaces when removal efficiency matters, and only using them as pre-filters for a rough cut of solids concentration; (v) understanding the impact on operational costs when evaluating a filtration vessel during a capital project purchase; and (vi) keeping up with advancements in filtration while simultaneously avoiding the temptation to conduct business as usual. Technical expertise and expert understanding of the science, properties, media and parameters affecting the filtration process, coupled with testing abilities and advances in technology, collectively point to the importance for the design of a reliable, efficient filtration solution.

7. Citations

[1] American Filtration and Separation Society, “Basic Solid/Liquid Separation Course”, 2-1, Cherry Hill, NJ, April 1, 2019.

[2] Abrams, A. “Mud Design To Minimize Rock Impairment Due To Particle Invasion.” J Pet Technol 29 (1977): 586–592.

[3] Tiller, F. and W. Li, Theory and Practice of Solid/Liquid Separation, University of Houston (2002).

[4] Malvern Instruments, “White Paper: A Basics Guide to Particle Characterization”, 2015.

[5] Sparks, T and Chase, G. (2016). Filters and Filtration Handbook. Oxford: Elsevier/Butterworth-Heinemann.

[6] Perlmutter, B.A., “Principles of Filtration”, WER 5300 - Scientific and Technical Report, Pall Corporation, New York, NY, USA (1983).

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