Technical Article

Understanding Particle Removal Performance in Liquids with Cartridge and Bag Filtration

Overview

Cartridge and bag filters are commonly used in the food and beverage industry to control contamination in fluid process streams (liquid or gas), in order to preserve required product quality attributes such as optical clarity, particulate removal, microbiological stability, chemical stability, and organoleptic quality.

Given the wide array of products available, it is important to understand filter removal performance to ensure their effective and economical use in food and beverage industry applications.

The purpose of liquid filtration is for particle and gel removal or microbial retention. Bag filters achieve only the first goal, while cartridge filters can achieve both goals, depending on their type, either as particle removal filters or microbially validated membrane filters.

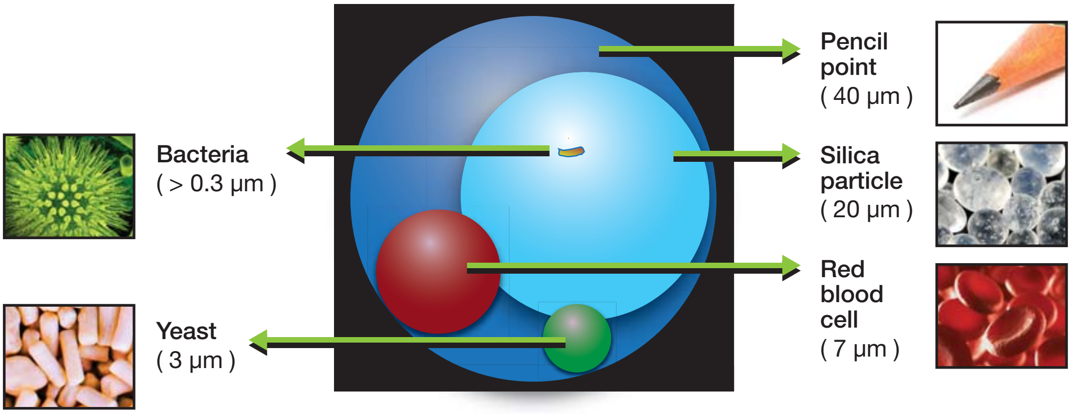
This article focuses on the particle removal performance of cartridge and bag filters in liquids[1].

Particle Filter Removal Performance in Liquids

In the food and beverage industry, suspended particles can be solid and hard, or soft and deformable. Their size distribution can be homogenous, with a narrow particle size distribution, or heterogeneous, with a wide particle size distribution. They range from sub-micron to larger sizes in the millimeter range and greater.

A micron is one-thousandth of a millimeter or one millionth of a meter. Particle sizes found in suspended solids in food and beverage applications span a very wide range. Microfiltration involves the removal of suspended solid particles and microorganisms from about 0.1 micron and greater. Particles which can be seen by the naked eye generally measure approximately 40 microns (Figure 1). A human hair measures 70 microns in diameter, while the head of a pin is about 2 mm (2000 micron) in diameter.

Figure 1: Relative Sizes of Small Particles



By contrast, soluble solids such as protein macromolecules, dissolved sugars, and mineral ions in water cannot be removed by these types of filters. These require the tangential membrane processes of ultrafiltration, nanofiltration and reverse osmosis.

Cartridge and bag filters are developed and validated by filter manufacturers to achieve a certain degree of removal performance. Unfortunately, the absence of standards regarding the validation testing, removal ratings and removal performance in the filtration world often causes the improper selection of these filters.

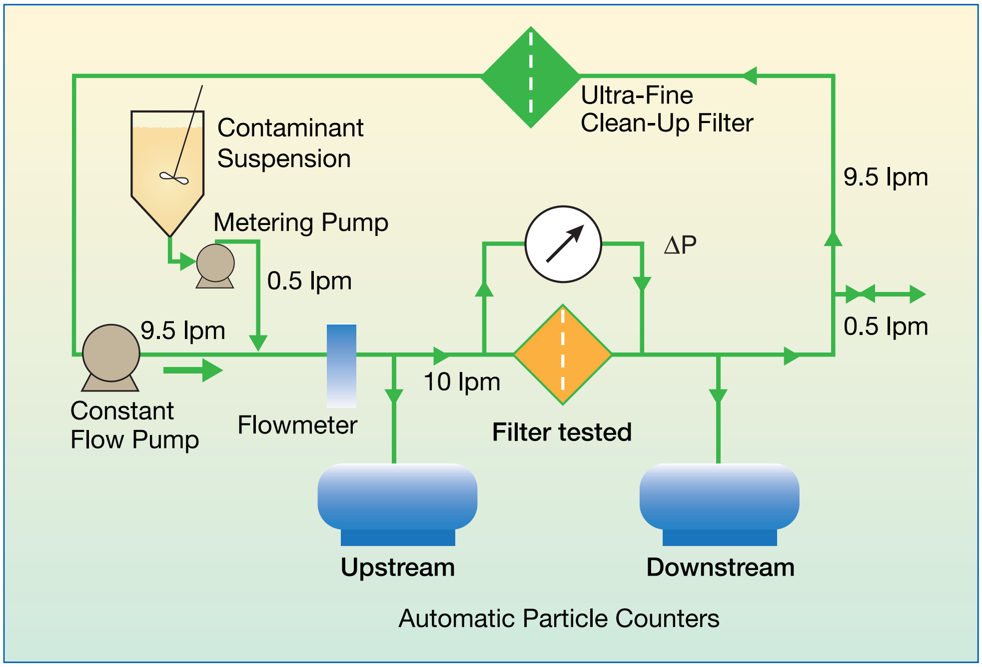
Measurement of Particle Removal Performance

Filter manufacturers determine particle removal performance based on laboratory tests which expose the filters to carefully controlled suspensions of standardized particles of known mass or size distribution, such as fine or coarse silica test dust, glass beads, latex spheres or polystyrene beads, *i.e.* usually hard spherical particles. These particles have little to do with the morphology of microorganisms and measurements based on these should not be used to make any statements about microbial performance of filters, as microorganisms do not behave like particles. For example, a 0.2 micron particle removal filter is not equal in performance to a 0.2 micron validated microbial filter. Correct validation of microbial filter performance is not based on the same challenge methods.

The tests used to generate the particle removal data, such as the use of single pass or multiple pass challenge tests, the type of challenge particles used, and the measurement methods (mass or particle size counts) must be considered carefully in order to understand the true performance of a particle-rated filter. For example, challenging a fine filter with coarse test dust would hardly show a relevant performance indication. Or, describing removal performance based on a gravimetric determination (mass) of particles which pass the filter as opposed to measuring specific particle counts in the filtrate would yield different results. The sensitivity of the optical counters used for particle counts is important. It is difficult to compare filter removal performance when test methodology differs.

A classical test method used is a modified OSU-F2 test which is based on ISO 4572, ANSI B.93.31-1973 (single pass test, Figure 2). A single pass test means that the test suspension challenging the filter only passes the filter once, representative of how most filtration occurs in real-world food and beverage industry applications. The filtration occurs at a constant flow rate, with a specific particle concentration, and with particles of a known size distribution. Measurement is based on particle counts using highly sensitive optical counters in the feed fluid and in the filtrate.

Figure 2: Schematic of Modified OSU-F2 Test Stand for Measuring Particle Removal Performance



“Nominal” and “Absolute” Filters

Common terms used to loosely define filter particle removal performance are “nominal” and “absolute”. These terms refer to the removal solely of particles and should not be used to describe filters used for microbial removal. These terms are also extremely relative, and do not specify true particle removal performance. Instead, filter removal efficiency based on particle counts, or the Beta ratio should be used to quantify and compare filter performance.

Particle removal efficiencies are expressed, based on a given particle size, as the relationship between an upstream and a downstream particle count at a given micron rating (x) or larger. Particle removal efficiency is calculated as:

$$\frac{(\text{Influent particle count}_X - \text{Effluent particle count}_X)}{\text{Influent particle count}_X} * 100\%$$

Example: A filter which is challenged with 1000 particles that are 3 microns and larger in size (x=3), and lets only 1 particle pass through has a removal efficiency of 99.9% at 3 micron or larger.

$$\frac{(1000\text{-}1)}{1000} * 100\% = \frac{999}{1000} * 100\% = 99.9\%$$

Removal efficiency is also expressed as a Beta ratio at the given micron rating. In this example the Beta ratio is 1000 at x=3 microns or larger.

$$\frac{\text{Influent Particle Count}}{\text{Effluent Particle Count}} \text{ or } \frac{1000}{1} = \text{Beta } 1000$$

The Beta ratio defines exactly what filter performance is expected. Figure 3 illustrates two examples of filtration outcomes, depending on the Beta ratio of the filter selected.

Figure 3: Illustration of Beta Value Determination

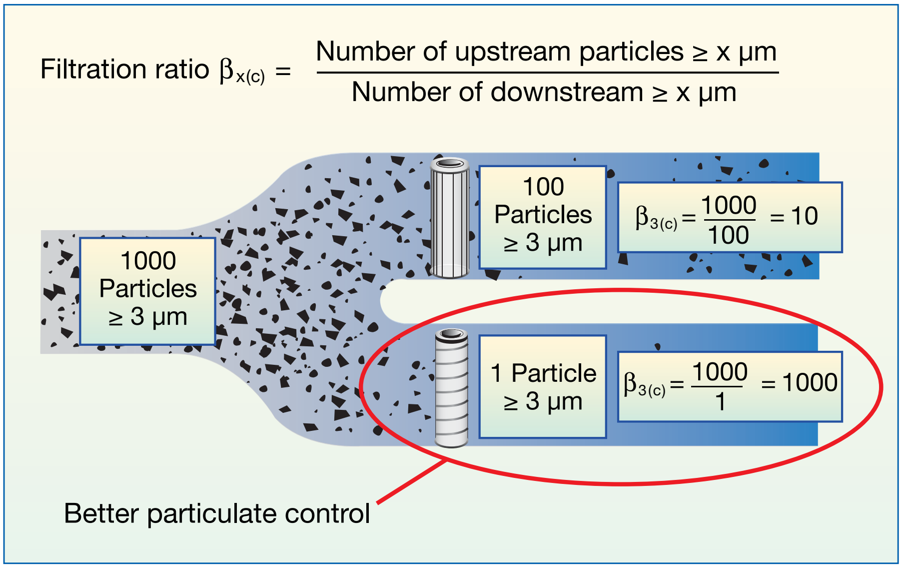


Table 1 shows how different filters can be compared to one another based on removal efficiency or Beta ratio.

Table 1: Comparison of Filter Particle Removal Performance at ≥ 3 Micron

Filter	No. of Particles / ml @ ≥ 3 micron Influent Particle Count	 Effluent Particle Count	Removal Efficiency[1]	Beta Ratio[2]
Filter A	5000	500	90%	10
Filter B	5000	250	95%	20
Filter C	5000	50	99%	100
Filter D	5000	5	99.9%	1000
Filter E	5000	1	99.98%	5000

[1] [(Influent particle count – Effluent particle count)/ Influent particle count] * 100%

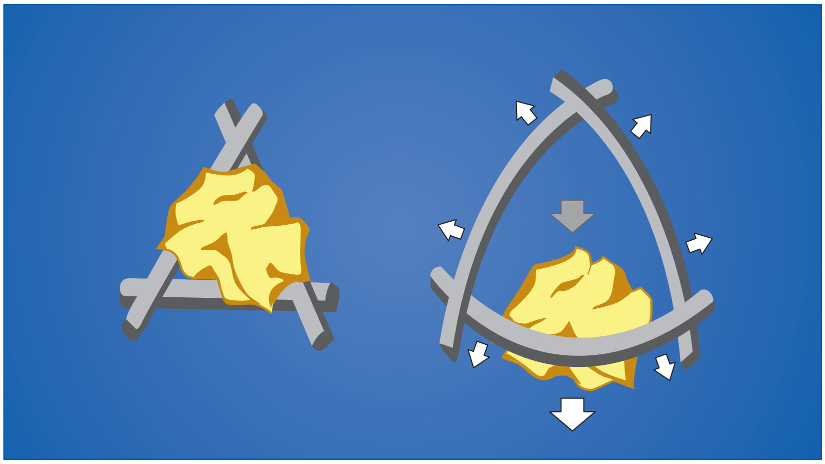
[2] Influent particle count/Effluent particle count

By contrast, there is no standard definition of what the terms “nominal” or “absolute” removal performance mean. While nominal always means a lesser removal performance than absolute, some filter manufacturers may consider nominal to mean any value at 99% removal efficiency or less, while others may consider a 98% removal efficiency to be absolute. It is therefore important to know the quantitative basis for the use of the terms “nominal” and “absolute” in order to truly understand removal performance.

Very nominal removal efficiencies might only be in the 60% range, a large performance difference from a 90% nominally rated filter. Better nominally rated filters tend to exhibit removal efficiencies of at least 90% (Beta 10) at a given micron rating. Where filter products are so nominal that no quantitative removal efficiency value exists, as with some bag filters, one should be aware of the filter’s limitations.

The term “nominal” additionally may refer to inexpensive filters with fibrous media of non-fixed pore structure, which tend to flex or unload retained particles under rising or fluctuating pressure (Figure 4), display channeling (bypass in sections with large uncontrolled pore sizes) or even exhibit media migration. Due to unloading or channeling, these filters may appear to offer a long service life, as their differential pressure remains static for long periods as the filter is not adequately removing contamination, which is contrary to its purpose. Examples of such filters are string wounds, fibrous, non-fixed media filters, low-end melt blown polypropylene filters and many bag filters especially those with sewn seams. These filter types tend to display variable, non-reproducible filtrate quality, and may have arbitrary removal performance ratings.

Figure 4: Schematic of Contaminant Unloading



On the other hand, there are filter types with nominal removal performance which have a fixed pore structure, due to the rigidity of their media construction. They would perform better than the filters with non-fixed pore structure in that they would not unload their contaminants or be subject to channeling or media migration. Examples of these are higher quality melt blown polypropylene filters or high quality fixed pore melt blown bag filters with welded seams and leak-free sealing into the bag housing. Nominal filters with fixed pores have absolute ratings at large particle size.

The term "absolute" refers to a filter with stable media structure due to fixed pore construction, with reproducible, specific and constant removal efficiency, fixed particle size cut-off, no media migration, and no tendency to unload. Such filters typically display equal to or greater than 99.9% (Beta 1000) efficiency, with high-end filters for highly critical applications displaying at least 99.98 % (Beta 5000) at a given micron rating. The absolute rating of a filter indicates the diameter of the largest hard, rigid particle that would pass the filter under defined test conditions.

Filters that do not fit well into their housings of course would not live up to their published removal efficiencies or Beta ratio, as any bypass of fluid at the filter sealing points would compromise the expected performance.

To further develop the concept of removal performance, we take a look at filter removal performance at different micron ratings. In practical applications, particles in fluid suspensions exhibit a range of micron sizes. A given filter actually has different removal efficiencies or Beta ratio values when challenged with different particle sizes.

For example, a filter is challenged with a given test suspension and its performance is characterized by the results shown in Table 2.

Table 2: Filter Removal Performance – Challenged with Different Particle Sizes

Particle Size in Test Suspension (microns)	Influent Count	Effluent Count
40	1,000	0
20	4,000	0
10	20,000	4
5	30,000	55
1	40,000	9,500

The same filter could be characterized in a variety of ways:

- as an absolute 10 micron and greater filter with Removal Efficiency of 99.984% or Beta 5000 [(25,000-4)/25,000 = 99.984%]
- as an absolute 5 micron and greater filter with Removal Efficiency of 99.89% or Beta 1000 [(55000-59)/55000 = 99.89%]. This example is shown in Table 2, wherein the sum of influent counts at or greater than 5 microns in size is compared to total effluent counts
- as a nominal 1 micron and greater filter with Removal Efficiency of 89.94% or Beta 10 [(95,000-9559)/95,000 = 89.94%]

For the same particle distribution and for the same filter, different filter performance information can be published.

Table 3 summarizes the concepts discussed regarding "nominal" and "absolute" removal performance.

Table 3: Nominal and Absolute Particle Removal Filters

Particle Removal Filters	
“Nominal” Filters	**“Absolute” Filters**
May or may not have removal efficiency data	Always have removal efficiency data
Removal efficiency data based on gravimetric or particle count analysis	Removal efficiency data based on particle count analysis
Lesser particulate control, typical Beta ratios (if available) at 100 or lower	Better particulate control, Beta ratio for critical or highly critical applications at 1000 or 5000
Non-fixed pore or fixed pore construction	Stable, fixed pore construction
May exhibit unloading, channeling, or media migration leading to variable, non-reproducible removal performance (non-fixed pore construction)	Reproducible, specific, constant removal performance
Useful in less critical or non-critical applications	Useful in critical applications

Conclusion – The Right Filter for Each Application

Proper filter selection means choosing the right filter for a given purpose. There are appropriate situations for specifying “nominal” versus “absolute” high Beta ratio filters.

The filters on the lower end of the performance spectrum provide clarification (solids removal, turbidity reduction), and some protection of downstream particle filters and downstream processing steps, with nominal filters of fixed pore construction providing much improved protection. They can be cost-effective and appropriate in less critical applications generally located upstream in a process. High Beta ratio filters are ideally suited in the later stages of a process, *e.g.* for protection of final membrane filters or critical end of process particle removal applications.

Understanding cartridge or bag filter removal performance enables a proper selection and comparison of filter offerings for process applications. In addition, taking a holistic view regarding true cost of ownership as opposed to filter cost alone enables users to make informed choices for the right filter combinations to achieve their goals.

Footnotes

[1] Pall Technical Article: “Understanding Particle Filtration in Liquids in Food and Beverage Industry Applications”

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