The NanoCeram® Primer

A Guide to Understanding the NanoCeram® Advantage

Presented by

Argonide Corporation

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What is Pore Size & How Do I Know What is Best for Me?

The current rating systems for filters combined with the wide variety of cartridge filters that are commercially available can make selection of the right one for a specific application a challenging task. Before selecting a cartridge, it is important to understand cartridge filters, how they work, how they are rated, and how technology is paving the way for new ways to consider filtration efficiencies.

Ratings

RATINGS

The pore size corresponding to an 85% removal is generally called the Nominal Rating of the filter. However, different manufacturers rate their nominal values differently.

For our purposes here, an Absolute Rating is the pore size where 99.9% filtration efficiency is achieved. However, and this is important, the definition of absolute pore size varies from filter manufacturer to filter manufacturer. In theory, an absolute pore size rating for a filter is based on the largest challenge particle, usually a glass bead, which will pass through the filter. Nothing larger than this rating should pass through the filter. Others may define this based on log reduction as we do. For example, if the filter can reduce a particle size by 3-log (or 99.9%), then that would be the applied absolute pore size rating.

For example, bacteria are larger than 0.2 microns, so an absolute rating of 0.2 implies sanitization capability. But this doesn't cover virus, most of which are smaller than 0.2 microns.

Electropositive Filters

ELECTROPOSITIVE

Most filters separate particles by the mechanisms of sieving, inertial impaction, interception and diffusion. This is true of most membranes as well as fibrous depth filters. Electropositive filters principally use adsorption (electro-adhesion) as the filtering mechanism, one that has actually been used for decades, both as membranes and in a fibrous depth filter.

Electropositive membranes have several disadvantages including a very low dirt-holding capacity, tendency to foul quickly, low reliability (any flaw in its surface can lead to breakthrough) and high costs for materials, maintenance and actual operation. On the other hand, a highly efficient fibrous filter that is electropositive and has a high flow is much more difficult to achieve.

NanoCeram® is an electropositive fibrous filter media *with high particle removal efficiency* as well as *high dirt holding capacity.* When incorporated into a *pleated filter,* its *flowrate is equivalent to, or higher than pleated filters that are rated at 3 microns.* NanoCeram®'s absolute rating is 0.2 microns, yet the flow through a standard 2.5" diameter x 10" high cartridge is 10 gpm @ an initial pressure drop less than 2 psi. High flow rates (Figure 1) are a characteristic of NanoCeram® filters.

Figure 1 – Flow Rates of NanoCeram Pleated Filter Cartridges.

Part No. *(Size)*		**P2.5-5 or PAC2.5-5** *2.5" x 5"*	**P2.5-10 or PAC2.5-10** *2.5" x 10"*	**P2.5-20 or PAC2.5-20** *2.5" x 20"*	**P2.5-30 or PAC2.5-30** *2.5" x 30"*	**P2.5-40 or PAC2.5-40** *2.5" x 40"*	**P4.5-10 or PAC4.5-10** *4.5" x 10"*	**P4.5-20 or PAC4.5-20** *4.5" x 20"*	**P4.5-40 or PAC4.5-40** *4.5" x 40"*
Suggested Flow Rate	(GPM) (LPM)	2 7.5	4 15	8 30	12 45	16 60	10 38	20 76	40 152
Peak Flow Rate *	(GPM) (LPM)	5 19	10 38	20 76	30 114	40 151	25 95	50 189	100 380

*** Peak Flow Rate based on initial flow using new filter cartridge and clean water during laboratory testing.**

What is DHC & Why Does it Matter?

Dirt holding capacity ("DHC") generally refers to the capacity of a filter cartridge to retain a given weight of particles before the cartridge plugs. Logic dictates that for a given pore size, the larger the particle challenging that filter, the greater would be the DHC (based on how long it takes for that filter to plug) as smaller particles would simply pass through the larger pores.

However, there are few applications where capturing those smaller particles don't have significant value.

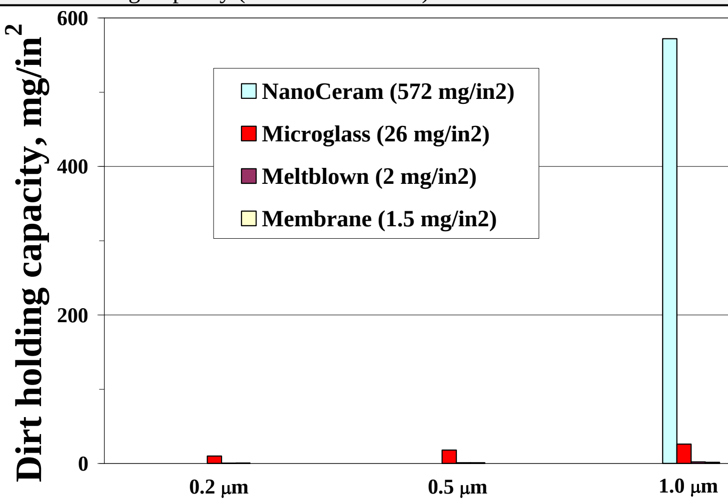
Much like a standard filter, the NanoCeram® electropositive fibrous filter media mechanically sieves particles larger than its average pore size. However, the NanoCeram® *also* adsorbs *smaller* particles throughout its entire fibrous structure, resulting in DHC levels many times greater than standard filter cartridges. In other words, if you were to weigh the amount of "dirt" captured by a NanoCeram filter cartridge versus other filter cartridges, the NanoCeram filter would far outperform the standard filter (see Figure 2).

As a "broad spectrum" particle adsorber, the NanoCeram® cartridge removes both coarse particulate as well as fines. For example, in applications currently using a 3 micron cartridge, the NanoCeram® will remove 3 micron and larger particulate with a similar efficiency to the 3 micron sediment cartridge. Yet, when the two cartridges are weighed and compared after operating under identical conditions and for the same period of time, the NanoCeram® will have removed several times the quantity of particulate (by weight) than the standard sediment cartridge. The difference is that NanoCeram® will remove virtually all of the sub-micron particles that pass through a conventional filter.

In many applications, removing sub-micron particles is vital. They are responsible for much of the fouling of reverse osmosis (RO) membranes, and would degrade the efficiency of ultraviolet (UV) and ozone disinfection systems. Unfiltered fines and colloidal matter can also affect chemical processes and impact the quality of the surfaces of precision products.

Membranes are surface filters with very little DHC. Consequently, while their efficiency might be high, their capacity for holding dirt will often lead to premature fouling resulting in frequent cleaning cycles and increased operational costs.

Figure 2 – Dirt Holding Capacity (A2 Fine Test Dust) of NanoCeram versus other Filter Media



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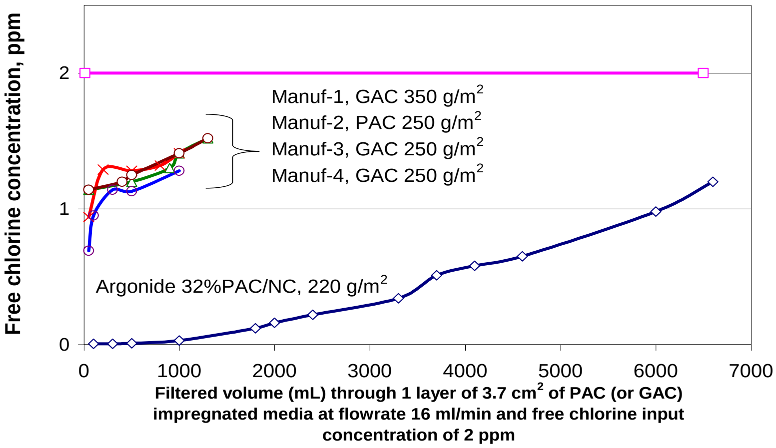
What is NanoCeram-PAC?

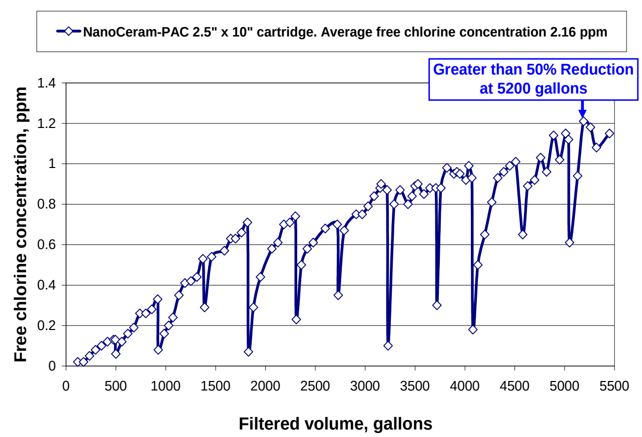
Activated carbon has been used for years to improve the quality/taste of drinking water. Typically GAC (granular activated carbon) is used in a packed bed or is combined into a filter media. To incorporate these carbon granules into a filter media requires adhesives or a starch additive to keep the carbon from washing out; or the carbon granules can be enmeshed into a foam system.

Figure 3 – Dynamic Adsorption of Chlorine by NanoCeram-PAC versus other carbon-based Filter Media.



NanoCeram-PAC represents a paradigm shift in carbon filtration in that fine activated carbon powder (-625 mesh) can now be utilized in filter media as it is held within the structure by electroadhesive forces, without using adhesives or starches that would blind or possibly deactivate the carbon. As compared to media containing GAC, PAC offers a much greater external surface area resulting in much more rapid adsorption of soluble contaminants (Figure 3).

Figure 4 – Chlorine Adsorption Capacity for NanoCeram-PAC.



Contaminants removed include chlorine, iodine and soluble organics that may be highly toxic or may cause unpalatable taste and odor. The result is much greater adsorption efficiency at moderate to high flow rates and/or with thin beds of media, such as a single layer pleated cartridge (Figure 4).

The full line of NanoCeram-PAC pleated filter cartridges combine high efficiency particulate filtration as found with the original NanoCeram filters, with this high efficiency (powdered) activated carbon (PAC) - all in a single depth media. As a result, each NanoCeram-PAC™ filter cartridge offers a unique combination of efficiency, capacity, flowrate & low pressure drop for both particulate and chemical adsorption or for soluble contaminants such as soluble organics and chlorine. Their best use is in those applications where a combination of fouling-resistant soluble contaminant removal and particulate reduction is desired.

Figure 5 – Drinking Water

TESTED AND CERTIFIED UNDER INDUSTRY STANDARDS Water Quality

This product has been tested and certified to meet NSF/ANSI Std. 53 for Material Safety only.

Testing performed by the Water Quality Association has determined that this product reduces Cysts by at least 99.97%.

For drinking water applications, the entire line of standard-sized NanoCeram-PAC filter cartridges have been certified to the NSF/ANSI Std. 53 for Material Safety only. Further testing by the WQA determined that these filter cartridges reduce Cysts (parasites) by at least 99.98% (Figure 5).

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How Long Will My NanoCeram Cartridge Continue to Work?

How long a filter will last is a very common question, but a difficult one to answer. Several factors can affect life, but the overriding factor is the load and type of particles being filtered. Particulate contaminants may include colloidal inert matter, inorganic particles such as metal oxides, natural organic matter (NOM), total organic carbon (TOC) to include humic/tannic/fulvic acids, endotoxins, bacteria, cysts, virus, etc. New EPA (in the United States) regulations require that the turbidity (defined as a cloudy condition in water due to suspended silt or organic matter) of municipal water must be reduced to less than 1 NTU (Nephelometric Turbidity Units).

The volume of water treated to meet the required NTU limits and/or the pressure drop that is developed, provide useful metrics for the lifespan of a cartridge (Figure 6).

Figure 6 – Filter Life in Municipally-Treated Water for NanoCeram & NanoCeram-PAC Filter Cartridges.

Part No.	**P2.5-5 or PAC2.5-5** *2.5" x 5"*	**P2.5-10 or PAC2.5-10** *2.5" x 10"*	**P2.5-20 or PAC2.5-20** *2.5" x 20"*	**P2.5-30 or PAC2.5-30** *2.5" x 30"*	**P2.5-40 or PAC2.5-40** *2.5" x 40"*	**P4.5-10 or PAC4.5-10** *4.5" x 10"*	**P4.5-20 or PAC4.5-20** *4.5" x 20"*	**P4.5-40 or PAC4.5-40** *4.5" x 40"*
Capacity before first detection of NTU (sensitivity 0.01 NTU) when challenged by local municipal water @ 1.0 NTU								
Gallons *(Liters)*	42,000 *(158,500)*	102,000 *(385,500)*	204,000 *(770,000)*	306,000 *(192,750)*	408,000 *(1,156,500*	234,000 *(885,000)*	480,000 *(1,815,000*	640,000 *(3,630,000)*
Capacity until flowrate ceases when challenged by 1.0 NTU local municipal water								
Gallons *(Liters)*	72,000 *(273,000)*	174,000 *(660,000)*	348,000 *(1,320,000*	522,000 *(1,980,000*	696,000 *(2,640,000*	399,000 *(2,394,000*	810,000 *(3,060,000*	1,620,000 *(6,120,000)*

The answer is even more complex when discussing soluble contaminants such as chlorine. In this case, flow velocity (the speed at which water flows through a set surface area of media, often in terms of cm/sec) is a very important metric.

All carbon-based products require "residence time" for contact between the contaminant and the carbon itself. The longer the contact time, the greater the dynamic adsorption rate of the carbon for soluble contaminants. This is why the smaller particles of PAC used in NanoCeram-PAC filters offer such an advantage. The huge surface area of such small carbon particles means that available surface area to adsorb the chlorine is enormous (more capture sites). Therefore, the "bounce-back" capacity of the PAC allows for higher flow rates to attain chlorine adsorption rates which would be comparable to GAC-based filters running at much slower flow rates. The static capacity for such filters is still quite high (Figure 7) and is further enhanced by NanoCeram-PAC's particulate adsorption capacity.

Figure 7 – Chlorine Reduction Capacity of NanoCeram-PAC Filter Cartridges.

Part No.	**PAC2.5-5** *2.5" x 5"*	**PAC2.5-10** *2.5" x 10"*	**PAC2.5-20** *2.5" x 20"*	**PAC2.5-30** *2.5" x 30"*	**PAC2.5-40** *2.5" x 40"*	**PAC4.5-10** *4.5" x 10"*	**PAC4.5-20** *4.5" x 20"*	**PAC4.5-40** *4.5" x 40"*
Capacity for > 50% Reduction of Chlorine (from 2ppm to < 1ppm) @ Flow Rate = 1 gpm/ft^2 PAC Media.								
Gallons *(Liters)*	2,100 *(7,950)*	5,200 *(19,500)*	10,800 *(41,000)*	16,000 *(60,500)*	21,600 *(82,000)*	12,700 *(48,000)*	26,000 *(98,250)*	52,000 *(196,500)*

How Do I Determine My Filter's Efficiency?

Although not often used in today's world of filtration, it is useful to offer a brief discussion of Filtration Efficiency Percentages. Efficiency is an indicator of how well a filter controls particulate: i.e., if one out of every two particles (> 0.5 μ) in the fluid passes through the filter, the efficiency at 0.5 μ = 2; if one out of every 200 of the particles (> 0.5 μ) passes through the filter the efficiency = 200.

Therefore, filters with higher efficiency retain more particles of a given particle size. Efficiency for a given particle size is also dependent on the quantity of the particle size in a water stream.

Figure 8 – Filtration Efficiency of NanoCeram.

Particle Size	NTU	Efficiency
0.2 μ	10	> 99.9%
0.5 μ	100	> 99.99%
1.0 μ	250	> 99.9996%

NanoCeram® filter cartridges exhibit a level of unmatched efficiency given their high flow rates and low pressure drop. This efficiency is attributed to the strong electropositive forces that capture particulates many times smaller than the media's relatively large pore size. NanoCeram®'s efficiency has been determined through laboratory testing with a given particle size of latex beads (typically used for filtration R & D), their concentration (stated in NTU) in a flowing stream, with the resulting efficiency stated as a percentage of particles removed (Figure 8).

How Does Electroadhesion Work?

The Technical Explanation

Electroadhesion utilizes the difference in charge that may exist between a surface (or fiber) and a particle in an aqueous solution, where a charge is built up by the double layer effect. The zeta potential is a measure of the driving force between the particle and the fixed surface, acting to attract or repel the two. Most bacteria and most other particles are electronegative in water. Smaller particles also tend to become more electronegative. So an electropositive fixed surface would be far more effective at attracting and retaining particles than one that is electronegative. Another factor is the area of solid surface that is exposed to the particles in the fluid. One with a large surface area can support more electropositive charges and therefore adsorb more particles.

The NanoCeram® Advantage

The electroadsorptive ingredient in the NanoCeram® filter is a nano alumina fiber that has a surface area from 350-500 m^2/g, with virtually all of that on the outside surface of the fiber and exposed to the entire spectrum of particulate in an aqueous stream (Figure 9). Such high surface areas are unattainable either in a membrane or in a fibrous filter even where nanofibers are being used. Nanofibers are very difficult to manufacture much below a 100nm diameter versus a 2nm diameter in the case of nano alumina.

And even if a nanoalumina fiber with a 2nm diameter were commercially available, this fiber (and virtually every other nanomaterial) would have a very strong tendency to agglomerate with the other nanofibers. Once this agglomeration occurs, the advantage of that huge surface area is lost. The key to NanoCeram®'s advantage is that we've developed a novel method of grafting these submicron alumina fibers permanently to a scaffold. This serves to keep the fibers separate from one another so that each fiber can do what it is optimized to do . . . attract and capture submicron particles.

The nano alumina is attached to a larger microglass fiber scaffold and then formed into a non-woven filter that has a pore size of approximately 2-3 microns. The filter will retain particles larger than 2 microns by mechanical sieving. *Particles smaller than the average pore size are forced into the* *matrix where they are adsorbed.* The efficiency of adsorption is dependent upon the flow velocity, the particle size, and the bed depth. With a range from 5 - 9, pH is not a significant variable. Generally a pleated cartridge that has a filter thickness of 1 mm is capable of adsorption rates > 99.999% of bacteria, even smaller ones such as Klebsiella terrigena (0.5 micron). Adsorption studies with 0.2 micron latex spheres show that a pleated cartridge can be rated as an Absolute 0.2 micron filter.

Figure 9 – Filter Media Surface Area vs. Electroadsorptive (Active) Surface Area of NanoCeram Technology.

Part No.		**P2.5-5 or PAC2.5-5** *2.5" x 5"*	**P2.5-10 or PAC2.5-10** *2.5" x 10"*	**P2.5-20 or PAC2.5-20** *2.5" x 20"*	**P2.5-30 or PAC2.5-30** *2.5" x 30"*	**P2.5-40 or PAC2.5-40** *2.5" x 40"*	**P4.5-10 or PAC4.5-10** *4.5" x 10"*	**P4.5-20 or PAC4.5-20** *4.5" x 20"*	**P4.5-40 or PAC4.5-40** *4.5" x 40"*
Filter Surface Area	(in^2) (ft^2) (cm^2) (m^2)	200 1.4 1,290 0.129	490 3.4 3,160 0.316	1020 7.1 6,600 0.66	1530 10.6 9,870 0.99	2030 14.1 13,100 1.31	1,195 8.3 7,710 0.771	2,450 17 15,800 1.58	5,040 35 32,500 3.25
Electroadsorptive (active) Surface Area	**(in^2) (ft^2) (cm^2) (m^2)**	**8.8×10^6 61,000 5.70×10^7 5,700**	**2.16×10^7 149,700 1.39×10^8 13,900**	**4.88×10^7 339,000 3.15×10^8 31,500**	**6.73×10^7 467,000 4.34×10^8 43,400**	**8.93×10^7 620,000 5.76×10^8 57,600**	**5.26×10^7 356,000 3.31×10^8 33,100**	**1.08×10^8 750,000 6.97×10^8 69,700**	**2.22×10^8 1,540,000 1.43×10^9 143,000**

The NanoCeram® Value Proposition: Higher Price . . . Lower Cost

Here is the challenge. How do you present an item which may have a higher price tag than an alternative product, but provides other values such as longer life, better performance or higher reliability? The terms "cost effective", "lifecycle costing", "cost efficient", "cost of ownership" etc. all come to mind. Each of these terms recognizes that there may be value in a higher priced item.

For our purposes, we will refer to this as the Total Cost of Ownership (TCO). As a management tool, TCO modeling systematically accounts for all costs related to an investment decision. TCO models were initially developed by Gartner Research in 1987 and are now widely used in virtually every industry. Simply stated, TCO evaluates all costs, direct and indirect, incurred throughout the life-cycle of an asset, including acquisition and procurement, operations and maintenance, and end-of-life management.

In water filtration (historically, the value proposition incorporates known values of flow rates, ΔP, dirt-holding capacity, absolute ratings, etc.) the question of price vs. cost has been fairly well documented and is somewhat straightforward. This has resulted in the development, market maturation and the now relatively flat sales growth with venerable filters such as melt-blown, string-wound and even some membrane-based and pleated polypropylene products.

These types of filters can be considered "commodities" and attempts to improve on their performance are somewhat limited as these matured technologies typically make small incremental advances - if any. With this in mind, the principal market drive is price, and tends to be affected most by low cost labor content and/or substantial investment in automation which can be risky.

NanoCeram® filters offer a major cost benefit derived from the following advantages:

- Enhanced Operations – by removing fines in addition to the coarser particulate in a water stream, many industries will see dramatically improved performance
    - Highly efficient last line of defense for downstream processes and equipment
        - → Reverse Osmosis (RO) systems
        - → Ozone or UV disinfection systems
        - → Ultraporous membranes
        - → Carbon & resin beds
        - → Small aperture foggers & spray nozzles, pumps, waterjet cutting systems, etc.
    - Reduced microabrasions on finished goods will reduce reject rates.

- DHC – Capacity that can be hundreds of times greater than conventional filters
    - Fewer replacement elements;
    - Lower maintenance costs;
    - Less system downtime.

- ΔP – A lower pressure drop
    - Less energy consumed in forcing fluids through a "tight" filter media;
    - Less wear & tear on other system components;
    - Freedom to design additional processes into a treatment system as NanoCeram doesn't significantly add to the total pressure drop of a treatment regimen.

- Reduced Operational Costs – none of the ongoing operational costs of membranes
    - Capital intensive backflush systems and chemicals;
    - Energy consumption during backflush cycles;
    - Water waste;
    - Labor costs for cleaning operations;
    - Reduced system down-time versus membrane systems that require constant cleaning;
    - Hazardous waste disposal from the backflushing cycles.

"NanoCeram filters may have a higher price tag, but they cost a lot less to use"