

Micro-Media Filtration: Superior Pre-Filtration For Desalination Systems

Craig J. Brown, P.Eng. and Ashwin Thakkar, Eco-Tec Inc., Pickering, Ontario Canada
Lloyd Vaz (Technical Consultant), Thermax Ltd. (WWS), Pune, India

Introduction

To ensure trouble free-operation of seawater desalination systems, membrane manufacturers recommend removal of suspended solids to negligible levels, as even small amounts of solids adhering to the surface of the membrane elements may adversely foul the membranes, deteriorate permeate quality and reduce membrane life. The past two decades have seen a dramatic increase in the use of reverse osmosis desalination systems. RO systems are less forgiving in terms of pre-treatment than evaporation systems. The close spacing of spiral wound membranes results in trapping of suspended solids inside the modules. This is exacerbated by the fact that, RO membranes bear a surface charge which may cause fine solids to be attracted to the membrane surface. Once fouling begins, cleaning of the membranes becomes very difficult and the system may not return to original performance levels once fouling has occurred.

According to one manufacturer, “membrane fouling in RO systems is as all-pervasive and inevitable as the common cold”.¹ In fact, many of the failures experienced by these systems can be traced back to inadequate pre-filtration.

Pretreatment Requirements

The level of suspended solids removal ahead of a reverse osmosis system depends on the concentration and nature of the

contaminants as well as how the system is to be operated. Higher concentrations of suspended solids will obviously necessitate more frequent membrane cleanings.

The concentration of un dissolved material in water can be measured and expressed in several ways. For relatively high concentrations, a gravimetric procedure is normally used to determine the *total suspended solids* (TSS). However, TSS measurements are not accurate for the low solids levels found in filtered water. Turbidity measurements, expressed in nephelometric turbidity units (NTU), provide quick and easy measurements. This method is only semi-quantitative though, and does not have a direct relationship to TSS. In addition, turbidity measurements are not valid at extremely low solids concentrations.

The membrane manufacturers recommend certain SDI levels to ensure a low fouling potential of the RO design. The silt density index (SDI) was developed as a means of predicting the propensity of given water to foul a reverse osmosis membrane. While it is also only semi-quantitative and cannot be correlated directly to TSS, it nevertheless has practical significance and is ideal for measurement of waters with extremely low TSS levels. Membrane manufacturers typically specify maximum SDI's of less than 4 or 5. Recently, the trend has been to reduce the SDI specification to less than 3.5. It has even been suggested² that an SDI of lower than 3 is necessary for trouble-free RO operation. Such a level of pretreatment

would likely to be very difficult achieve with conventional filtration systems.

According to one manufacturer of membrane cleaners, the SDI test does not adequately simulate the hydraulics of spiral wound RO elements and as a result claims that the SDI test does not reliably predict fouling potential. As a result, a value referred to as a *Cross Flow Fouling Index* (CFI) was developed³. For example, with a feed water turbidity of less than 0.2 NTU and a CFI of less negative than -0.17, quarterly RO systems cleanings may be expected.

Pre-filtration Technologies

Although there is no such thing as a standard pretreatment process, the most prevalent RO pretreatment has been direct media filtration using one or more layers of granular media such as sand and/or anthracite with coagulation. According to Cline¹ conventional depth media filtration is most efficient at removing materials down to 10-20 microns. If particle size distribution evaluations indicate that a high proportion of solids are smaller than 10 microns, supplemental filtration should be considered to deal with finer solids. For this reason, media filters are often supplemented with membrane cartridge filters.

Under conditions of optimal coagulation and system operation, multi-media filters provide excellent performance. However, consistent operation is somewhat difficult to obtain in practice in many instances. Such filters typically undergo a *ripening* period when they are first put into service after a backwash, during which time water quality is inferior. Moreover, while the filtrate quality tends to improve as the cycle proceeds, termination of the cycle normally sees an increased pressure drop accompanied by a breakthrough or leakage of turbidity. One of the keys to successful

operation is an effective backwash (i.e. cleaning) cycle. Long-term performance can deteriorate due to a slow buildup of solids in the media over many cycles, ultimately resulting in the creation of *mud balls*.

One of the major advantages of depth media filtration is that the cost of media replacement is extremely low, since the life is long and the media itself is inexpensive. It is also not prone to fouling and is generally considered to be very robust. Together with a reasonable initial capital cost, this explains the prominent place that this pretreatment technology has held for so many years in the industry.

Nevertheless, many in the industry are suggesting that the overall performance of media filters is inadequate for reliable reverse osmosis performance. In order to provide improved TSS removal for reverse osmosis, microfiltration⁴ and ultrafiltration⁵ membranes have been proposed and are seeing increased application. Membranes provide a barrier to suspended solids and ensure consistently low levels of TSS to downstream processes. The downside is that these processes tend to have higher initial capital costs and operating costs for periodic membrane replacement are appreciable. Moreover, in some cases, membrane pretreatment may just move the fouling problem upstream.

Spectrum Micro-Media Filter Design

An advanced media filter configuration called *Spectrum*, that utilizes a very fine 'polishing' or 'micro' media has been developed. The Spectrum Micro-Media Filter attempts to address some of the limitations of conventional media filters while improving filtration efficiency to levels approaching that previously achievable only with membranes.

The Spectrum filter is basically a two layer depth media filter. There are a number of features which depart significantly from the conventional design. Its main design features are as follows:

Coarse upper layer

The top layer consists of approximately 30 inches (76 cm) of coarse anthracite. This material is similar to, but somewhat finer than that used in a conventional dual media filter. As with conventional dual layer filters, the top layer provides the bulk of the solids retention and therefore defines the run length.

Fine Micro-media lower layer

The lower layer of the Spectrum Micro Media Filter is a significant departure from the conventional design. Whereas dual media filters typically employ about 8 inches (20 cm) of silica sand with an effective size of about 0.35 mm, the Spectrum filter uses a layer of high density media with an effective size of less than 0.1 mm. The lower layer removes the residual quantity of fine suspended solids not retained in the upper layer and therefore effectively defines the filtration efficiency. Photographs of the micro-media and conventional fine silica sand are shown in Figure 1.

High service flow rate

Service flow rates are significantly higher with the Spectrum filter. The range is 12-18 US gpm/ft² compared to normal maximum of about 8 gpm/ft².

Smaller diameter vessel

As a result of the higher flow rate, the diameter of the filter vessel required to treat a given flow of water can be reduced.

Simultaneous air scour/backwash cleaning cycle

Most media filters use a simple water backwash, wherein the filter is taken out of service and a flow of water is passed up through the filter bed to expand the media. This allows collected dirt to disengage and be flushed out the top of the filter.

This is frequently inadequate however, as dirt can adhere quite tenaciously to the surface of the media particles, particularly when coagulant is employed. Cleaning efficiency can be improved by agitating the media with air before the backwash. This scours the media by abrading the particles together. With the Spectrum Filter, the air scour is further enhanced. Water is first drained to the top of the media. Air and water are then passed simultaneously up through the media bed. The water flow reduces the weight of the media and allows the air to agitate the media much more violently and uniformly. When the vessel has been refilled with water, the air is turned off and a water backwash flushes dirt from the filter in the usual manner. The Spectrum Filter cleaning cycle is illustrated in Figure 2.

Low backwash flow rate

The smaller media particle diameter reduces the terminal settling velocity of the media and allows the use of lower backwash velocities - typically less than 50% of a conventional filter. Since the higher service flow allows the use of smaller vessels, the backwash flow rate can be as little as 25% of a conventional filter. This allows the use of smaller backwash pumps. When two filters are installed on a job, part of the filtrate flow from one filter can be used to backwash the other filter online. In this case a backwash tank is not required. This is not feasible with a conventional filter since the backwash flow of a conventional filter is typically more than twice its service flow.

The reduced backwash flow is also advantageous where the backwash water is recovered.

Somewhat higher pressure drop

The higher service flows and finer media result in a higher initial (i.e. clean) pressure drop across the filter. The typical pressure drop is approximately 30 psi (0.2 Mpa) as compared to approximately 5 psi (0.03 Mpa) for a conventional filter.

Shorter Service cycle

Although the dirt holding capacity of the Spectrum filter, which is defined primarily by the upper layer, is similar to that of a conventional filter, the service cycle is shorter because of the higher service flow rate.

The essential differences between a conventional dual media and the Spectrum Micro-media are summarized in Table 1.

Filter Performance

The concentration of solids leaving a media filter under different conditions can be roughly predicted using the following equation⁶.

$$\frac{C_e}{C_o} = \frac{k(Vd^3H)}{L} \quad (1)$$

Where:

- C_e = effluent TSS concentration
- C_o = influent TSS concentration
- V = flow rate (m³/m²/h)
- H = head loss at breakthrough (MPa)
- d = effective size of media (mm)
- L = bed depth (cm)

Table 1: Comparison of Conventional Dual Media Filter to Spectrum Micro-Media

	Conventional	Spectrum MM Filter*
Fine Media particle □(mm)	0.35	0.1
Lower Bed height (cm) (in.)	20 (8)	20 (8)
Service flow (m ³ /h/m ²) (gpm/ft ²)	20 (8)	29-44 (12-18)
ΔP (clean to dirty) (psi)	5-15	15-30

**This Spectrum Filters' Micro Media is specific for Water Filtration, and is referred to as SMMF-W*

It should be noted that the TSS of the filtrate is extremely sensitive to the particle diameter of the filtration media. By employing a finer media in the lower layer of the filter it is therefore possible to dramatically reduce the TSS of the filtrate. As expected, an increase in flow rate will tend to increase the filtrate TSS, however this can be easily compensated by a

reduction in media particle size. The Spectrum Filter typically uses service flow rates 2-3 times higher than conventional dual media filters.

A comparison can be made between a conventional dual media filter design and the Spectrum Filter by substituting the information from Table 1 in equation 1 and taking the ratio of the outlet concentrations.

$$\frac{C_{e(\text{Spectrum})}}{C_{e(\text{Conventional})}} = \frac{\frac{(d^3)(V)(H)}{(L)}}{\frac{(d^3)(V)(H)}{(L)}} = \frac{\frac{(0.1^3)(37)(0.1)}{(20)}}{\frac{(0.35^3)(18)(0.033)}{(20)}} = 0.144 \quad (2)$$

This indicates that, theoretically at least, the concentration of suspended solids in the filtrate from a Spectrum Filter should be 14.4% of that of a conventional dual media filter, despite the use of higher service flow rates and higher pressures.

Pilot plant tests were performed with synthetic feed waters to compare the performance of the Spectrum Filter with that of a conventional dual media filter. Feed waters were prepared by adding 10 mg/L of ISO fine test dust to tap water producing a turbidity level of approximately 5 NTU. The feed water was coagulated with 3 mg/L of poly aluminum chloride and the turbidity of the filtrate was measured online using a Hach Ratio 2000 online turbidimeter. Figure 3 shows the particle counter analysis of the feed water as well as the average filtrate. The particle removal efficiency at different particle sizes can be shown by taking the ratio of filtrate to feed particle counts. This is shown in Figure 4.

It can be seen from Figure 4 that the Spectrum MM Filter removes more than 99% of the particles 1.8 μm and greater. Studies have shown that the vast majority of particles (in natural water) have a size above about 1.5μm.⁷ On the basis of these remarkable results it would appear that this filter could indeed be classified as a ‘micro-filter’. This compares to the conventional filter which had a 99% cutoff at 7 μm. This is consistent with Cline¹. The relative performance seems to be reasonably consistent with the results predicted above by equation (2).

Table 2 summarizes the results from a series of pilot plant runs at different feed concentrations and different operating conditions. It can be seen that without any coagulant the Spectrum filter was able to remove about 90% of the solids from a feed containing [TSS] = 10 mg/L, reducing the turbidity to 1.12 NTU. The SDI was reduced to 4.5, which would normally be considered acceptable (although not optimal) for RO feed.

When 10 mg/L of Nalco Aluminex 1 coagulant (an inorganic salt) was applied to the same feed, the turbidity was reduced to 0.04 NTU and the SDI was reduced to 1.9. This would be considered excellent feed to any IX or RO system. Similar results were obtained at [TSS] = 25 mg/L. The filter was challenged with TSS levels of 100 mg/L and 200 mg/L. While the onstream time was reduced, the quality of the filtrate did not deteriorate.

An alternate coagulant was also evaluated. Nalco Aluminex 2 is a combination inorganic/organic coagulant. It produced even better results, producing an SDI of 1.0 from a feed containing [TSS] = 10 mg/L.

It should be pointed out that these tests were conducted on feedwaters which were largely synthetic. The feedwater contained only the 1 mg/L TOC present in the tap water makeup. It is known that high TOC levels can adversely effect coagulation and the final filter performance.

The results shown in Table 2 are averaged over the entire run. Unlike membrane filters, the performance of a media filter will vary over the duration of a service cycle. Figure 5 shows the turbidity over a the

initial portion of a typical filter run for the 10 mg/L TSS feed. The conventional filter exhibits the classical *ripening effect* at the beginning of the cycle where the initial quality is poor and gradually improves as the cycle proceeds. To ensure that only high quality filtrate containing less than 0.1 NTU is passed downstream, it is necessary to bleed the initial 15 column volumes of filtrate to waste over the first 120 minutes of the service cycle.

The Spectrum Filter, on the other hand, has virtually no ripening period, achieving a filtrate turbidity of less than 0.1 NTU within 2 column volumes and 7 minutes. It should be noted that short cycle times when treating high turbidity feeds are considered a major limitation for conventional media filters. This is because the ripening period begins to represent a major portion of the service cycle when treating high turbidity feeds. Because the ripening period for the Spectrum Filter is so short (~7 minutes) it is feasible to operate with service cycles of less than one hour.

The service cycle of a media filter is typically terminated by an increase in pressure drop and/or an increase in turbidity. Figure 6 show the entire service cycle of a conventional dual layer filter as well as that of the Spectrum Filter. Note that the end of the conventional cycle sees a significant turbidity breakthrough. No terminal breakthrough is exhibited by the Spectrum Filter. Apparently, as solids breakthrough the upper layer at the end of the cycle, they reach the top of the lower layer of micro-media, where they quickly blind the surface, but do not penetrate.

Note also that the volumetric throughput for each filter is the same. Because of the higher flow rate employed with the Spectrum Filter, the duration of its cycle is less. The onstream time for the conventional filter in this case was approximately 57 hours compared to 29 hours for the Spectrum. This would of course vary depending on the feed composition.

Table 2: Pilot Plant Results

COAGULANT	FEED TSS (mg/L)	Coagulant (mg/L feed)	MEAN SERVICE FLOW (gpm/ft2)	MEAN FILTRATE PURITY		
				NTU	TSS (mg/L)	SDI
No coagulation	10	0	17	1.12	1.1	4.5
Aluminex 2	10	12	18	0.03	0.0008	1.0
Aluminex 1	10	10	18	0.04	0.0008	1.9
“	25	12	17	0.03	0.010	2.2
“	100	12	18	0.03	0.011	2.4
“	200	12	18	0.04	0.0009	2.1

Organic Removal

Some vendors of ultra-filtration systems have made claims about UF capabilities in terms of TOC removal. It should be noted that most of the organic material found in natural waters has a molecular weight of less than 5,000. Typical UF membranes with molecular cut-off weight levels of 100,000 will not filter this material. They will remove only the small amount of very large molecular weight humic acids, algae, bacteria and viruses; that is, particles larger than their largest pore size. In fact, studies have concluded that “pretreatment [e.g., activated carbon or coagulation] before UF is necessary to achieve really significant dissolved organics removals”. “UF without pretreatment is not much better than conventional processes for removing DOC (Dissolved Organic Carbon) and is probably worse than conventional processes for removal of THMFP (tri-halomethane formation precursors).”⁸ For effective removal of naturally occurring organic matter, nanofiltration membranes with much lower MWCO are required.

To the extent that UF membranes do remove some natural TOC, it is well known that polysulfone UF membranes are very susceptible to severe, sometimes irreversible fouling by naturally occurring organic material.

Field Results

A number of Spectrum Filters have been installed in the field over the past few years, mostly on surface water applications. In addition to conventional surface water treatment applications, units have been installed on very challenging process applications such as pulp bleaching filtrates. A large system (900 m³/h (4000 gpm)) was installed (see Figure 8) in China on an oil field produced water application in 2002⁹.

The system continues to exceed its performance requirements and a second system (600 m³/h (2700 gpm)) is under construction.

A new ultra-pure water purification system was installed at the Pickering Nuclear division of Ontario Power Generation (Canada) in August of 2001 and began continuous operation in mid-September. The system treats shore-line Lake Ontario water withdrawn from the cooling water return duct. After coarse straining, the water is coagulated with polyaluminum chloride and filtered through Spectrum Micro-Media Filters. Following filtration, the water is demineralized by reverse osmosis units and then polished by Recoflo short bed demineralizers. The pre filtration system includes three 96 inch (244 cm) diameter Spectrum filters treating a total flow of 480 m³/h (2114 gpm). The Spectrum Filters at this installation are shown in Figure 7.

The OPG filtration system was designed to treat feed water with a typical turbidity of less than 1 NTU with very occasional spikes in excess of 100 NTU. It turned out that the turbidity of the feedwater was much higher than anticipated, particularly during the late autumn and winter months when high wind conditions are frequently encountered.

Despite the unanticipated high feed water turbidity levels, the Spectrum Filters have done an excellent job. Although the original intention was to use feedwater for backwash, due to the high feed turbidity, the system was modified to allow backwashing with filtrate. Final produced water quality has consistently exceeded the customers requirements. It appears as though a three month cleaning schedule of the RO modules will be more than sufficient to maintain optimum performance.

Another ultra-pure water treatment system was installed at Pleasant Prairie Power Station of We Energies at Wisconsin (USA) in October 2002. The system treats the

primary raw water source of Lake Michigan and include Spectrum Micro-Media filters followed by a skid mounted Recoflo demineralization system. The filtration was designed to treat feed water with a typical turbidity of less than 20 NTU with very occasional spikes in excess of 70 NTU. We

Energies' experience has been that these Spectrum Filters consistently produce water at 0.07-0.08 NTU from raw waters with up to 90 NTU. Incoming feed water turbidity and filtrate turbidity data over most of 2003 is summarized in Figure 9 and 10.

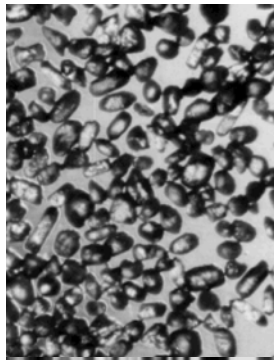
Summary

The Spectrum filter has a number of advantages over conventional media filters these include:

- Better average filtration efficiency, particularly in the 1-7 μm particle size range
- Very short ripening period
- No terminal turbidity breakthrough
- More effective cleaning cycle
- Higher flow capacity resulting in smaller filters
- Lower backwash flow requirements

The major disadvantage of the system are shorter onstream between backwashes (due to the higher flow rates) and higher pressure drop.

As a result of these advantages this filter should be ideal for pretreatment before reverse osmosis and packed bed ion exchange systems.



Spectrum Micro-Media
($<0.1 \text{ mm } \varnothing$)



Conventional sand
($0.35 \text{ mm } \varnothing$)

Figure 1: Lower layer filter media

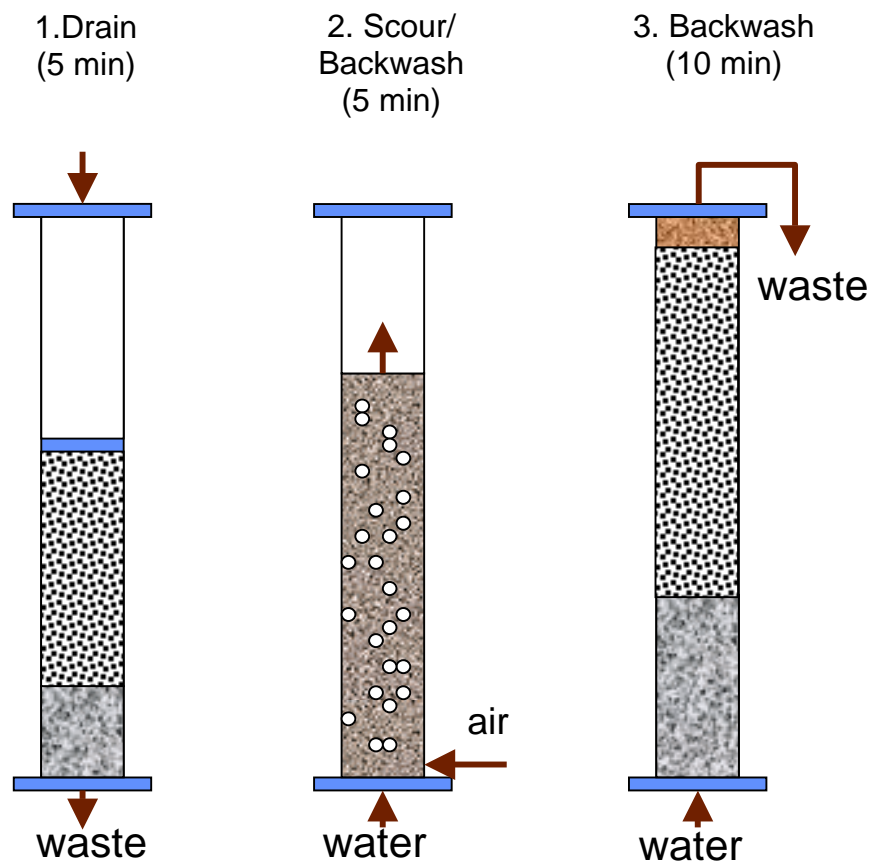


Figure 2: Spectrum Filter Cleaning Cycle

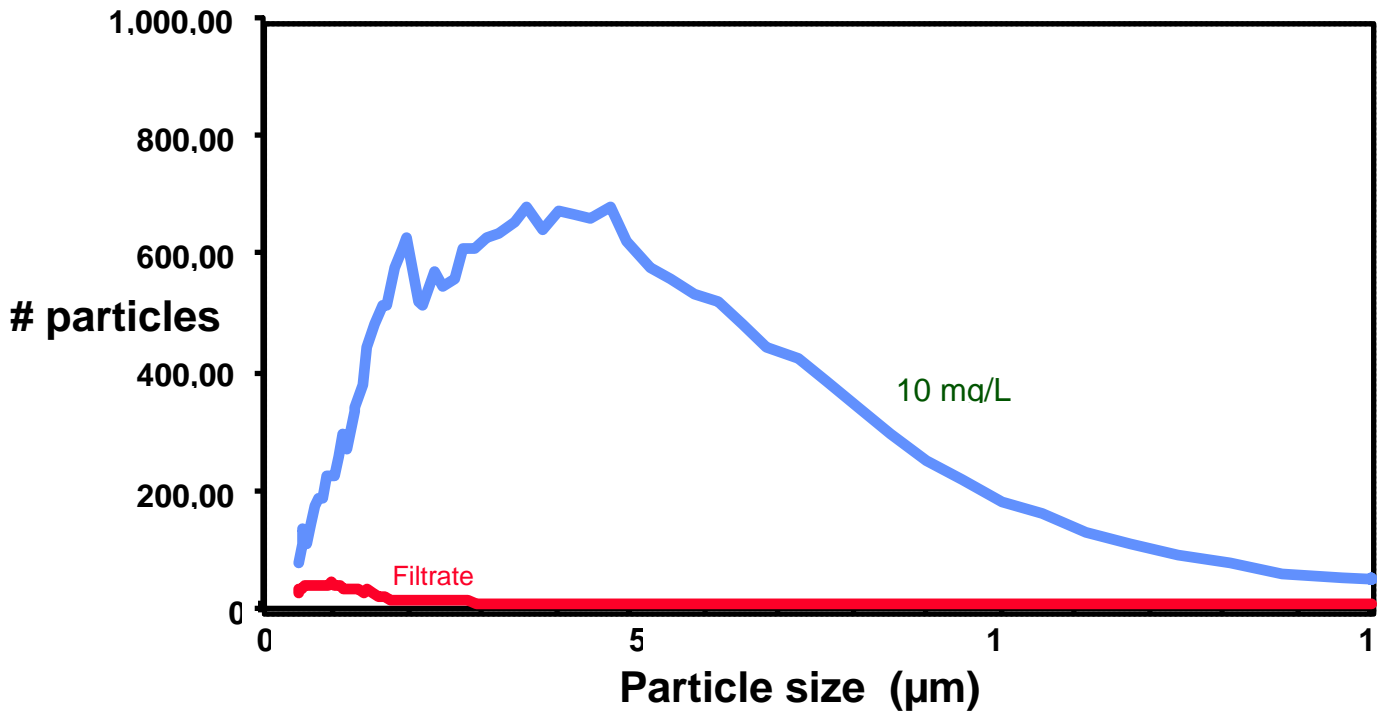


Figure 3: Spectrum Filter test feed and filtrate analysis

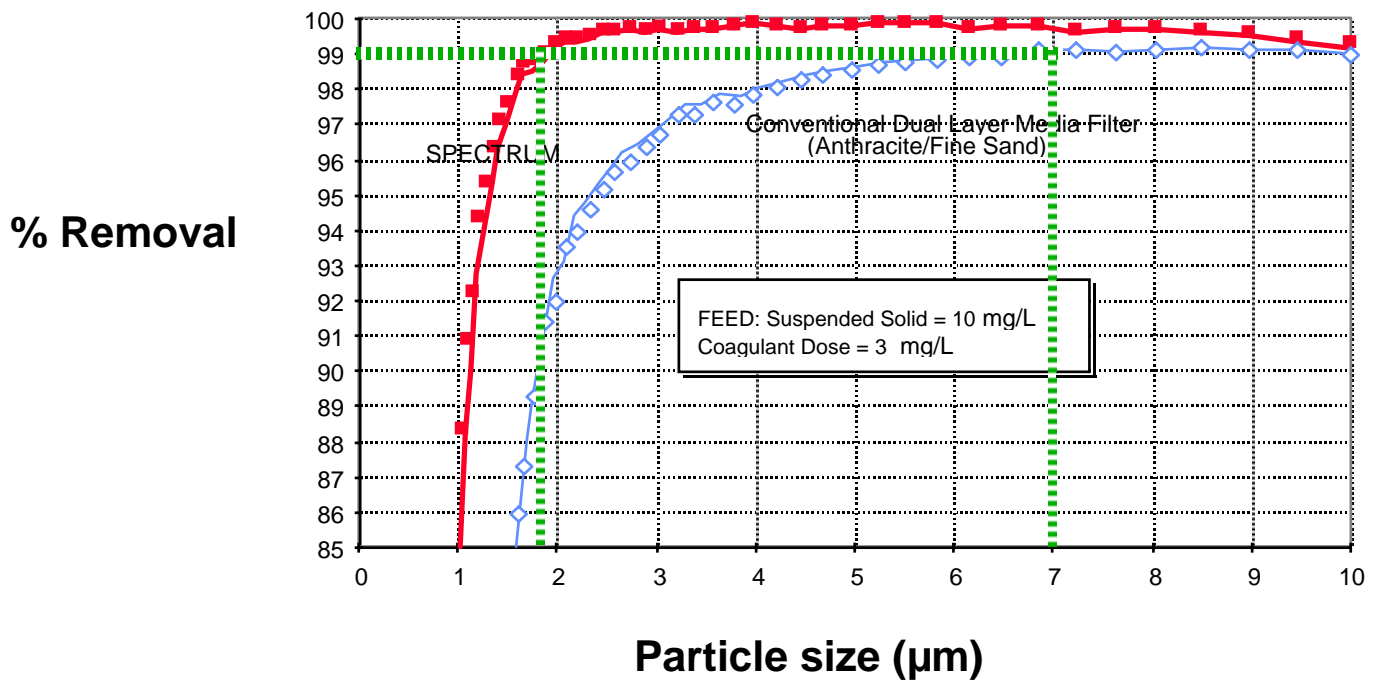
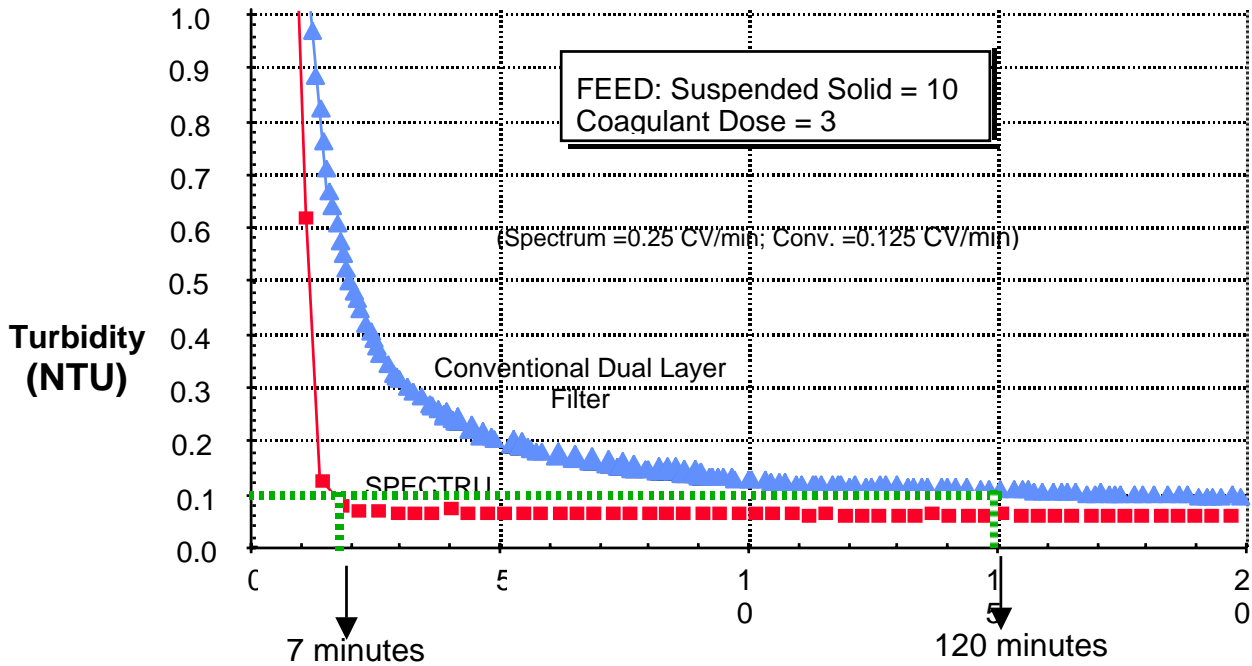
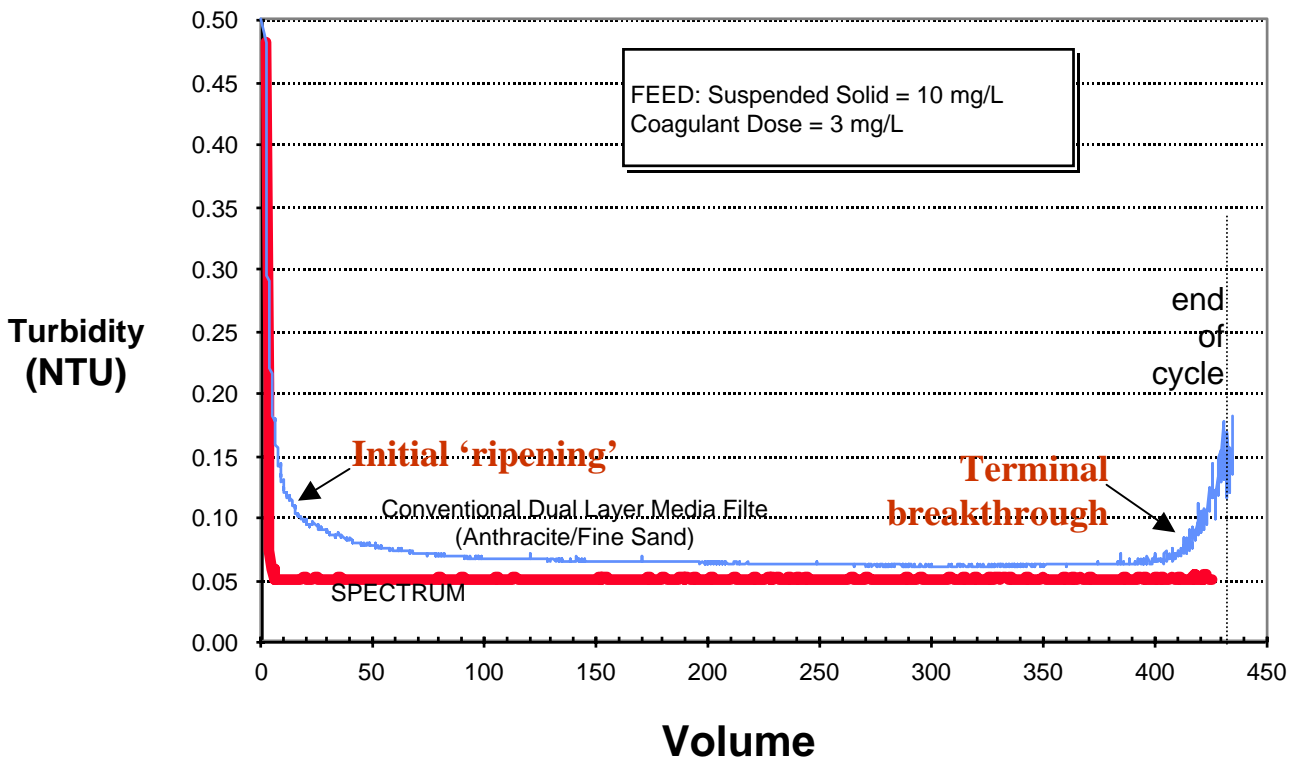


Figure 4: Filtration Efficiency: Spectrum filter vs Conventional dual media



Column Volumes
Figure 5: Filter Ripening



Volume
Figure 6: Typical Filter Cycle



Figure 7: Spectrum Micro-Media Filters at Ontario Power Generation, Pickering Nuclear



Figure 8: Spectrum Micro-Media Filters at Liohe Oil Field, China

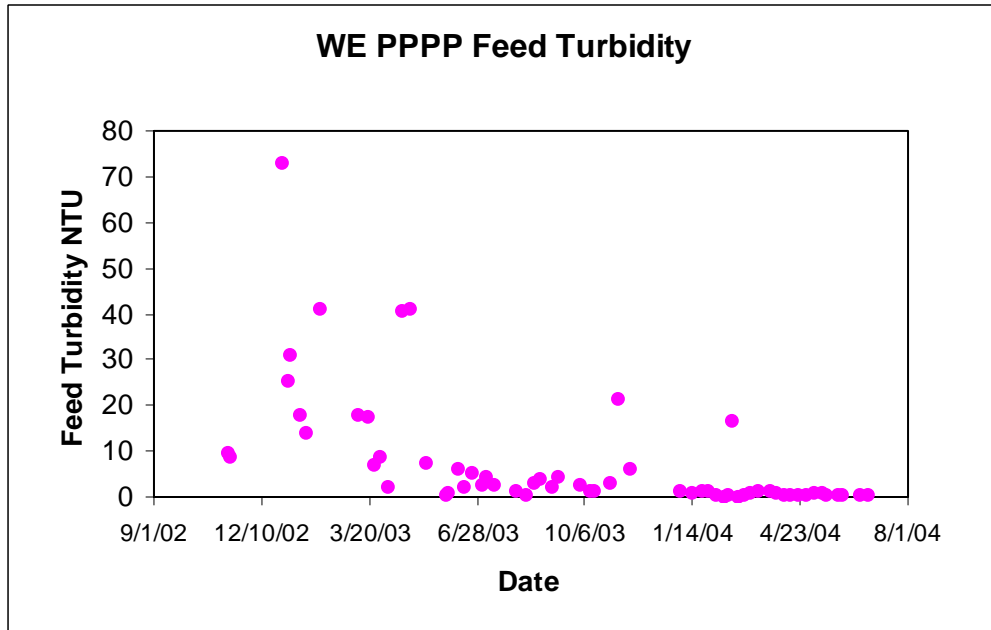


Figure 9: Spectrum MM Filter Feed Turbidity Levels -WEPCO

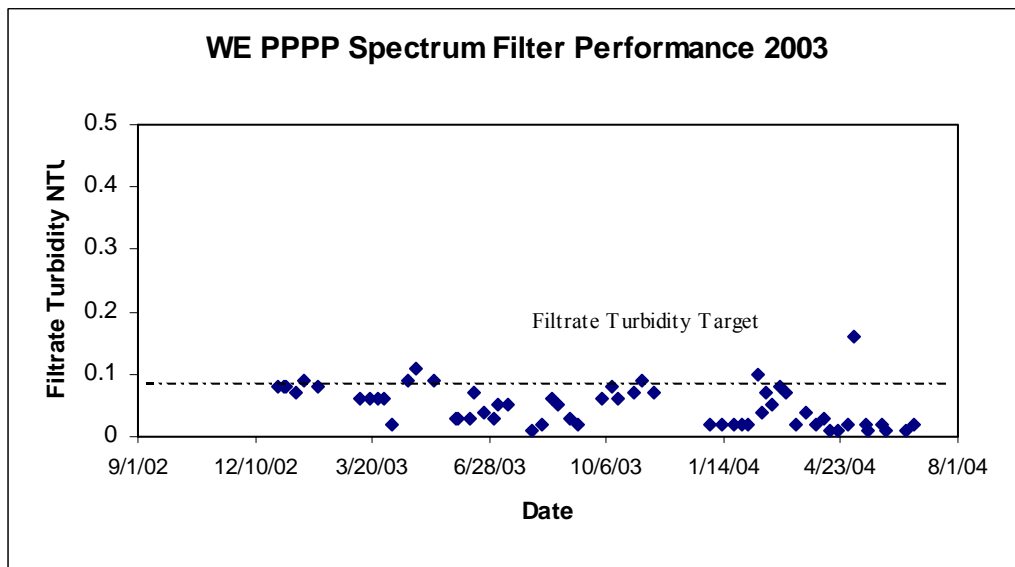


Figure 10: Spectrum MM Filter Filtrate Turbidity Levels - WEPCO

References

1. D.A. Cline, "Filtration Options for Pretreatment of Demineralization", *Proc. Of the International Water Conference*, Pittsburgh, PA, Oct. 2000.
2. N. Mulhern, "Death, Taxes and RO Membrane Fouling", *Water Technology*, 11/01/95
3. K. Sinha, 'Prepared Discussion of: Pretreatment Methods for Reverse Osmosis Systems", *Proc. International Water Conference*, Pittsburgh, PA, Oct. 2001.
4. D. Comstock, L. Durham, U.S, patent 5,198,116, Mar. 30 1993.
5. T. Tonelli, S. Kroll, "Microfiltration Technology - The Next Generation", *Proc. International Water Conference*, Pittsburgh, PA, Oct. 1997.
6. Monat, J.P. "Separation Systems - The Synergies Between Ultrafiltration and Ion Exchange" *Ultrapure Water*, July/August 1997, 33-38.
7. H. Hudson, "Water Clarification Processes", Van Nostrand Reinhold (1981)
8. C. Brown, J. Xiao, A. VandeBeck, "New Process for reusing Produced Wastewater" *Proc. International Water Conference*, Pittsburgh, PA, Oct. 2003.
9. M.M. Clark;, K.S. Heneghan, "Ultrafiltration of Lake Water for Potable Water Production", *Desalination* 80 (1991) 243-249.