An Alternative to Silt Density Index *(SDI)*…..
Continuous Particle Counting

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One of the biggest problems experienced with reverse osmosis (RO) systems is the need for frequent chemical cleaning and/or membrane replacement caused by colloidal fouling. These colloids also affect daily operations as seen by decreasing product flow over time, decreasing salt rejection, and increasing differential in membrane feed versus reject pressure. They may cause membrane failure because of uneven flow distribution and concentration phenomena within the cartridge (1).

Silt Density Index (SDI) has been the standard test to predict membrane fouling for many years. The method (ASTM D-4189) has been accepted worldwide. It has been a useful test, and often shows reasonable correlation with variations in RO performance attributable to colloidal fouling. However, there are some limitations to the test, and "variances" in plant operations can affect reliability, repeatability, and/or operational usefulness.

1. SDI is not continuous, on-line measurement.
2. Repeatability can be affected by differences in operator technique.
3. Test results can be very "scattered depending on upstream equipment operations at time/place SDI test is done.

Based on these limitations and variances, an alternative to SDI, or a "supplemental" method would be desirable. Preferably, a method that was on-line, continuous, had "multipoint" sampling capability, required no operator intervention……and, of course, was cost effective. On-line Particle Counters, and Particle Monitors have demonstrated the capability to meet these needs.

Background

Colloidal (particulate) fouling of reverse osmosis membranes is often traced back to the pretreatment system. These problems are sometimes the result of inadequate design, or improper operation. Inadequate design may be due to an inaccurate analysis of the water source, a change in the source, or increased product water needs without added pretreatment equipment. Oftentimes, fouling may occur simply due to the inadequate monitoring and control of upstream processes such as clarifiers, filters, etc. Membrane throughput is directly affected by deposits on the feedwater side. Production can be maintained, to a point, by increasing feed pressure, but operating costs increase, and membrane damage can occur. Before the maximum operating pressure is reached, membranes must be cleaned, either in place, or sent to another facility. If the plant does not have "excess" capacity, mobile units must be brought on site to maintain required production. This is a very expensive process.

SDI

Silt Density Index is a measurement, or "relative index" of the amount of particulates in water. The test consists of flowing a water sample through a 0.45 micron (µm) membrane filter at a constant 30 pounds per square inch gauge (psig) pressure. As the filter plugs, the unit measures the decrease in flow versus time. There is usually a close relationship between the SDI number and the rate at which colloidal and particulate fouling occurs. It is assumed that the test is mostly a measurement of colloidal concentration because large particulates affect the SDI the least when they are compared to the rapid plugging caused by smaller particles.

A typical warranty requirement for RO systems is an SDI of 5.0 for spiral wound membranes. Although the test is published in the American Society for Testing and Materials (ASTM) manual several "versions" have evolved to meet individual pretreatment system conditions. Other names have been associated with the test, such as "plugging index", "silting index", and "plugging factor". There is sufficient data to verify that the test provides a good correlation with changes in RO performance, at least for treatment of a particular water source. This correlation does not always hold true when comparing different waters and different sites (2).

The standard procedure uses a 47-millimeter diameter mixed cellulose esters filter with 0.45-µm pore size. Smaller diameter filters can be used as long as the collected volumes are adjusted in proportion to the filter area. Smaller pore sizes, such as 0.1 µm, are used if the SDI of a RO effluent is desired. Some operators have experienced variability in the test results on identical samples. The "cross flow" fluid dynamics in an operating RO are different from the "dead end" filtration on a SDI filter paper. Also, concentrations of ionic, organic, and biological materials on an RO membrane surface are very different than on the SDI filter surface. The interactions that can contribute to fouling are complex, and not well defined. Some procedures advise that two or more tests be ran to confirm results, and if there is a large difference, to run a third. These multiple tests can be discouraging to an operator because of the time required and deciding which result to believe. Some users have found a significant diff-

-erence in SDI results due to variances in filter paper properties. Thus, values obtained with filters from different manufacturers may not be comparable. A particle's surface charge can have a significant effect on whether it passes through the pore, or adheres and plugs the filter. Temperature affects water viscosity, which changes the flowrate through the filter. All of these "variables" affect the SDI value.

Particle Detection Instruments

Turbidimeters: "Light scattering" turbidimeters (nephelometers) have been the traditional on-line instruments used for monitoring/controlling the pretreatment systems of clarifiers, media filters, and carbon filters. However, as the demand for cleaner water increases, the need grows for more sensitive instruments. Turbidimeters do not provide the required sensitivity. In fact, water with a turbidity of 0.5 Nephelometric Turbidity Units (NTU) can contain hundreds of particles per milliliter (p/mL). Turbidity is defined as "an expression of the optical property that causes light to be scattered and absorbed, rather than transmitted in straight lines through the sample". Simply stated, turbidity is the interaction between light and suspended particles in liquid. It is not a truly quantitative value, but more of a relative value, or an "index" of water quality. An important property of NTU measurement is that for a given mass concentration of particles, the turbidity is less as particle size increases. This means that larger size particles could be in a sample, but not contribute appreciably to the turbidity reading.

Particle Counters: On-line, liquid particle counters have been used for many years in the "final product" stage of high-purity water systems. Some instruments detect particles in the submicron range. For example, in the microelectronics industry, particle size measurement down to 0.05 µm is often required. Injectable, pharmaceutical products are limited by federal regulations from exceeding specific numbers of certain size particles Large volume parentrals (LVP) may contain more than 5 p/mL larger than 25 µm, and not more 50 larger than 10 µm.

There is a size range of particles in water, which is difficult to remove in a multimedia filter. These particles follow stream lines of the water flow. Because their inertia is low, they do not settle with gravity as their mass is small, and they are too large to be affected by molecular (Brownian) forces. This size range is between 2.0 to 10.0 µm, which is above the size range where turbidimeters are most effective.

Particle counters measure the size and concentration of particles using "light blocking" methods with a laser diode as the light source. This is important information because it can be used to determine the effectiveness of different type filters. For example, if 5.0 µm particles are passing through a cartridge filter with a pore size rating of 1.0 µm, there must be an internal problem, or possibly the filter has been mislabeled.

Particle monitors: The particle monitor (PM) uses a unique "light fluctuation" technique that combines features and benefits of the turbidimeter and particle counter. It is an extremely sensitive, but simple device that gives a "relative" index of water cleanliness. The PM measures fluctuations in intensity of a narrow light beam (infrared LED) transmitted through a flowing sample. These fluctuations are caused by random variations in the number of particles in the light beam. Since only the AC component measures particle motion, it can be easily isolated and amplified. Turbidimeters produce a DC electrical signal that is proportional to the measured parameter. This makes the device susceptible to "drift" caused by DC noise, light source variances, and optical surface fouling. Sensitivity tests have shown that for particles larger than 2.0 µm, the PM has a detection capability 100 times greater than a turbidimeter. In fact, for a 5.0-µm particle, the PM can detect concentrations of less than 10p/mL (3).

There are several factors that enable the PM to be a very effective tool for operating the plant.

1. The useable measurement is not affected by particle size, shape, color, or composition. It gives an "index" of the number of particles per unit volume. The sensor is extremely sensitive to any particle that passes through the sample cell greater than 1 µm.
2. There is no calibration requirement.
3. The cost of a PM is lower than a standard particle counter.
4. Maintenance is accomplished by simply replacing the sample tubing. The sample does not contact any optic surfaces, which eliminates signal drift caused by fouling.

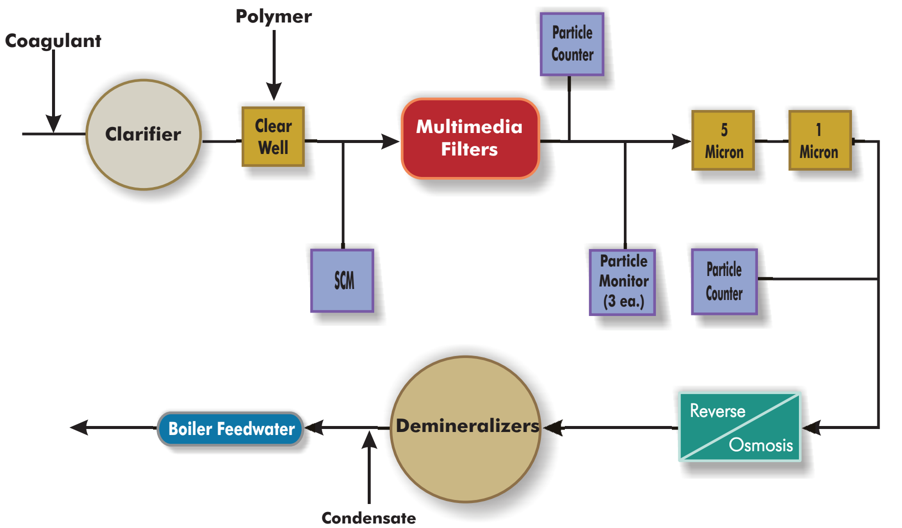
A Case History

An electric generating station installed an RO system in an effort to reduce demineralizer regenerations, and reduce wastewater disposal problems. The pretreatment system is shown in Figure 1. The water source is a small river that has rapidly changing turbidity. An intermediate settling/storage basin minimizes large turbidity swings in the clarifier inlet. The primary coagulant was originally alum, but was changed to a polymer/inorganic blend. Turbidimeters were used to monitor clarifier and filter effluents. The RO system consists of two trains with each having a primary and secondary set of membranes. Start-up flow was 250 gallons per minute (gpm) per train with a differential pressure of 36 psig. SDI tests were initially performed on a regular basis, but were eventually discontinued because of no useable correlation between SDI values and cleaning frequency.

Almost immediately after start-up (1994), the RO trains had to be cleaned often, usually twice a week, because of high differential pressure. The cost of membrane cleaning chemicals, manpower, and waste disposal was excessive.

Differential pressure also caused

Figure 1. Pretreatment System



the cartridge filters to be changed out often. Each of the 4 vessels contains 52 elements with each element costing approximately $100.00. A complete change out could cost up to $21,000. Over the next several years, attempts were made to solve the problems:

1. A particle "charge-modifying device" that (reportedly) prevents particulates from building up on the membranes was attempted. There was no improvement in membrane performance.
2. Different membrane manufacturers were evaluated. A new membrane was discovered that gave more flow with less fouling and lower differential pressure.
3. Anthracite was replaced with multimedia (anthracite, sand, garnet, quartz) to get better removal of small particulates. There was no "measurable" improvement in water quality going to the cartridge filters or the performance of the RO.
4. Different brands of cartridge filters were evaluated. Seven (7) brands gave varying results in performance and cost.
5. A chemical technology company was contacted to assess the entire coagulation/filtration process using on-line monitoring and control instruments....

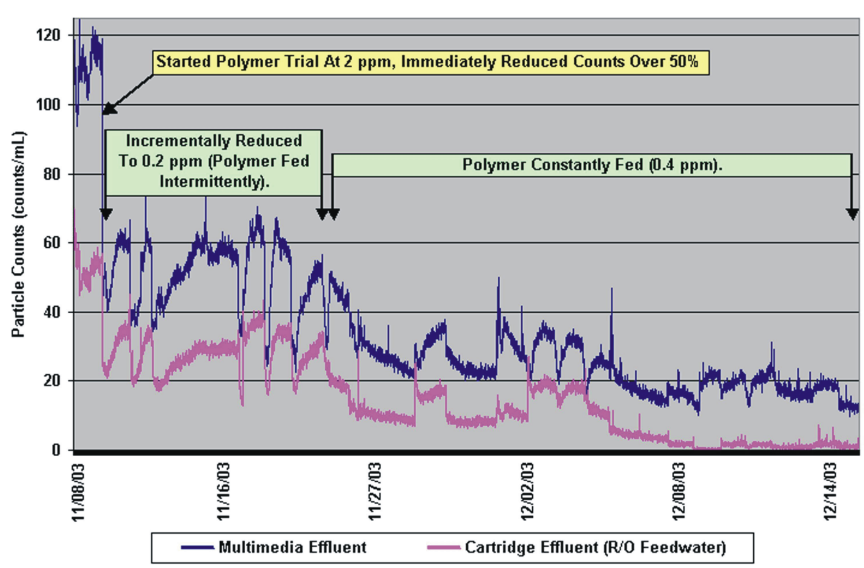
In October 2003, a supplier* was contacted to evaluate the coagulation/filtration process. A particle counter was used to check the effluent of each pressure filter. Two filters were shown to be passing a high number of particles and were removed from service. This change forced all of the flow to go through three filters, which matched the design capacity for multimedia. Particle removal improved 50%.

A program was then established to use particle counters and particle monitors to continuously measure performance of every system component. Particle monitors were installed on the effluents of the clarifier clearwell, first and second stage multimedia filters. These strategic installations allowed observation of how backwashes and flow changes affected filter performance. The particle counter was installed at the cartridge filter to monitor inlet and outlet particulate levels. The particle counter tracked the number and size of particles leaving the 5-µm and 3-µm filters. A small amount of cationic polymer was fed to the multimedia influent to improve removal of sub-micron particles. Although the counters/monitors do not detect particles below 1 µm, it is well established that colloids are adsorbed on filter media that is properly conditioned with the correct amount of the correct polymer. A streaming current monitor (SCM) was used to optimize the polymer feed to ensure that the minimum amount was being used. A polymer can also contribute to RO fouling if it is overfed (4).

Results are shown in Figure 2. Before polymer addition, particle counts in the filter effluent were more than 120 per mL. After the polymer addition, counts dropped to less than 20 per mL and almost (0) in the cartridge filter effluent. The polymer dose was approximately 0.4 parts per million (ppm) and an immediate improvement was seen in the RO operation. Cleaning frequency went from once per week to once per month. Feedwater pressure buildup was less than 2.0 psig after 30 days.

The particle counters and monitors also provided a couple of unexpected benefits. Operators found that changing filter backwash procedures reduced particulates in the effluent. This finding was not detectable us-

Figure 2. Treatment Results



ing turbidimeters. It was also discovered through the particle counter that the cartridge filter supplier had mistakenly shipped 3.0-µm filters instead of 1.0-µm filters. Currently, the plant is controlling multimedia filter operations with particle monitors and monitoring membrane feedwater with the particle counter.

Conclusion

The return on investment (ROI) of using sensitive and reliable on-line particle counters and particle monitors in high-purity water pretreatment systems can be substantial. Operators no longer have to rely on SDI "spot checks" to operate the plant. Savings in chemicals, filter replacements, and membrane cleaning/replacement can be quantified. Economic losses can be avoided in microelectronics and pharmaceutical production because of water associated problems. Boiler feedwater quality and boiler reliability can be ensured.

References

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Endnote

*Chemtrac Systems, Inc. of Norcross, GA., is the supplier mentioned in the text.

Author Robert L. Bryant is the president of Chemtrac Systems, Inc. He began his career with Nalco Chemical in 1969 and introduced streaming current technology to the water treatment industry in 1982. Mr. Bryant founded Chemtrac Systems Inc. in 1985. He has written more than 20 articles for technical publications and Chemtrac holds several patents on water instrumentation devices.