SELF-CLEANING PRE-FILTRATION FOR R.O. AND OTHER MEMBRANE SYSTEMS

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ABSTRACT

A few years ago physical processes could only remove *suspended* solids from a water stream. Recent advances in technology now allow the removal of selected *molecules* and *ions* from a water stream by physical means using membranes. The membrane process has recently become very efficient and economically feasible for many industrial, commercial, municipal and even residential customers. Because of the infinitesimally small entities dealt with in this technology, blinding of the membrane surface becomes a chronic problem. To maintain the efficiency of this technology, pre-treatment must remove the greater bulk of the suspended solids to allow the membranes to efficiently remove selected dissolved solids. Five-micron bag and cartridge pre-filters have traditionally been used to treat the influent to membrane systems. The inherent nature of the elements in these pre-filters has restricted them to one-time use then being discarded and replaced by new elements. Under many conditions these pre-filter elements may be useful only for a few hours before replacement. This replacement activity can be very labor-intensive and quite expensive. A very cost saving alternative is the use of automatic self-cleaning filters to remove the bulk of the suspended solids. These filters remove all suspended solids above ten microns achieving a nominal five-micron removal. This type of filter utilizes a weavewire screen mesh woven from 316-L stainless steel. Such filters are PLC controlled and automatically clean themselves based on a preset differential pressure across the screen. Units with a footprint of four square feet are capable of filtering hundreds of gallons per minute to below ten microns. Because there is only one moving part during the short cleaning cycle and no mechanism comes in contact with the screen element, maintenance and repair

are minimal. Installation requires only an electrician to bring power to the filter unit and a plumber to bolt the filter's inlet and outlet flanges into the piping system. No pneumatic or hydraulic lines are required. Another great advantage of this technology is the fact that filtered water is continuously supplied to the membrane system even during the twenty-second cleaning cycle without duplicity. Other models using "thread" technology can boast three-micron removal. Self-cleaning pre-filtration drastically reduces the operational costs of membrane filtration systems and paves the way for economically increasing the trend in America, and elsewhere around the world, for water reuse. This trend is being propagated by the exponentially growing demands of industrial, municipal and commercial establishments for limited water supplies. Many areas of the U.S. and world are tapping fixed deposits of freshwater or depleting freshwater at a rate greater than it can be renewed constituting the *mining* of this precious natural resource.

TERMS AND DEFINITIONS

Filtration: The term *filtration* can be defined in its simplest form as the process of removing solid particles from a fluid (liquid or gas) by forcing the fluid through a porous medium through which the solid particles cannot pass. The filtration spectrum divides solid particle sizes into five segments ranging from sub-molecular ions to macro particles. See Table 1 for examples of each range.

RANGE	**SIZE**	**EXAMPLES**
Ionic	<0.001 micron	Ca^+, Cl^-, Fe^{++}, Na^+
Molecular	0.001 - 0.1 micron	Sugar, Virus, Gelatin
Macro-Molecular	0.1 – 1 micron	Tobacco Smoke, Bacteria
Micro-Particular	1 – 10 micron	Red Blood Cells, Flour
Macro-Particular	10 – 3500 micron	Pollen, Beach Sand

Table 1: Filtration Spectrum (Ref. 1)

Filtration Degree: The smallest particle size requiring removal from the fluid stream in a specific application is called the *filtration degree*. Two conventions are used to define filtration degree. One is taken from the textile industry referring to the density of threads expressed as the number of threads per linear inch. This definition uses the term "mesh" to describe the filtration degree. In the field of filtration the term has come to mean the number of pores or openings per linear inch in a woven media. Although still in common use, the term "mesh" is not a true parameter of measurement since the actual opening or pore size of such a medium depends on the diameter of the threads or wires and the type of weave used in the manufacturing process. The second convention used to describe *nominal* filtration degree, preferred in the industrial arena, is an actual linear dimension of the *shortest* distance (length or width) across an individual opening or pore of the filter medium. This is most often given in microns; i.e. 1/1000 of a millimeter or 0.00004 of an inch. A common reference for the size of a micron is to remember that the average human hair is about 100 microns in diameter. The *absolute* filtration degree is the length of the *longest* straight-line distance across an individual opening of the filter medium.

<u>Effective Filtration Area:</u> The total area of the filter medium that is exposed to fluid flow and is usable for the filtration process is referred to as the *effective filtration area.* Any structural member or other solid barrier that prevents fluid flow and particle separation from occurring over any surface area of the filter medium, such as structural supports, is not included in the effective filtration area.

<u>Filtration Open Area:</u> The *filtration open area* is the pore area or sum of all the areas of all the holes in the filter medium through which the fluid can pass. Filtration open area is often expressed as a percentage of the effective filtration area. The type of filter medium can affect this greatly as shown in Table 2.

FILTRATION DEGREE	**SCREEN FILTRATION OPEN AREA**	
	WEAVE WIRE	**WEDGE WIRE**
500 micron	43%	33%
200 micron	37%	13.3%
100 micron	32%	6.6%

Table 2: Filtration Open Area

<u>Total Suspended Solids (TSS):</u> Particle load or *total suspended solids* (TSS) is of major concern in membrane pre-filtration. TSS is often defined as the concentration of total solid particles that fail to pass through a 1.2-micron laboratory filter and is expressed in milligrams per liter (mg/L) or parts per million (ppm). (Ref. 2)

<u>Particle Size Distribution (PSD):</u> If along with TSS the *particle size distribution* (PSD) is known, the concentration (or volume) of particles removed from the fluid by a filter is readily determined for a given filtration degree. PSD is given in particle counts (particle density) per size unit, usually in one-micron increments. PSD can also be given in percent volume of TSS (volume density) per size unit. The latter means of expressing PSD is much more useful in designing pre-filtration for membrane systems.

<u>Membrane:</u> With regards to water treatment, a *membrane* is a thin, pliable semi-permeable material used to separate contaminants from fluid water. The size of contaminants removed is directly related to the size of pores in the membrane.

<u>Macrofiltration:</u> The term *macrofiltration* refers to the removal of non-dissolved, non-colloidal particles 1.0 micron and larger from a fluid stream. This is the

common type of filtration used as the pre-treatment for membrane systems. Membranes are typically not needed for this filtration degree.

Microfiltration: *Microfiltration* is the process of removing particles, mostly colloidal, from a fluid in the size range of about 0.1 micron to around 1.0 micron using membranes. These particles are typically referred to as colloidal particles. (Ref. 3)

Ultrafiltration: The point where colloids become dissolved solids is the lowest filtration degree for *ultrafiltration* membrane technology. Typically this type of membrane system removes particles between 0.01 and 0.1 microns. (Ref. 4)

Nanofiltration: As the name implies, *nanofiltration* is the membrane technology that removes contaminants down to around 1 nanometer (0.001 microns) in diameter. (Ref. 4)

Hyperfiltration: *Hyperfiltration*, more commonly known as Reverse Osmosis (RO) utilizes the "tightest" membranes used in filtration. Nearly all dissolved solids are removed by hyperfiltration systems. These membranes can remove substances (sub-molecular ions) with diameters less than 0.0001 microns. (Ref. 4)

Turbidity: *Turbidity* is an expression of the optical property that causes light to be scattered rather than transmitted in a straight line through a water sample.

Colloids: Particles with sizes ranging between 0.01 and 1.0 microns are sometimes considered a subset of suspended solids and are referred to as colloids. (Ref. 3)

Silt Density Index: *Silt Density Index (SDI)* is an index calculated from the rate of plugging of a 0.45-micron membrane filter at a constant applied gauge pressure. SDI can be used to determine effectiveness of various processes such as filtration used to remove particulate matter.

INTRODUCTION

Water treatment using membrane technology has exploded in the last two decades. New technologies resulting in reduced capital and operating costs for membrane systems have recently caused accelerated growth in the membrane market. However, membrane systems are not inexpensive and every month added to the life of the membranes themselves greatly improves the ROI of the system. Therefore, water *pre-treatment* is a must for membrane longevity and system performance.

Traditional pre-treatment systems consisted of granular media or multi-media depth filtration systems with bag or cartridge pressure filters between these systems and the membranes. European technology perfected the weaving of fine stainless steel wires into a square weave screen with close tolerance openings of 10 microns in 1996. This paved the way for self-cleaning automatic screen filters to operate as pre-filters for Reverse Osmosis and other membrane systems. These filters can now remove all contaminant 10 microns in size and larger and many particles down to 1 micron or even less under some circumstances.

Self-cleaning mechanical screen filters are easier to maintain and operate than granular media filters, have a much smaller footprint for a given flow rate, utilize less energy and use 40-80% less flush water for a given flow rate. Also, there is no possibility of media carryover. Mechanical screen filters don't stop filtering during the cleaning cycle so redundancy is not required to provide a constant supply of pre-filtered water.

Figure 1 shows an example cutaway of a self-cleaning mechanical screen filter as described in the following text.

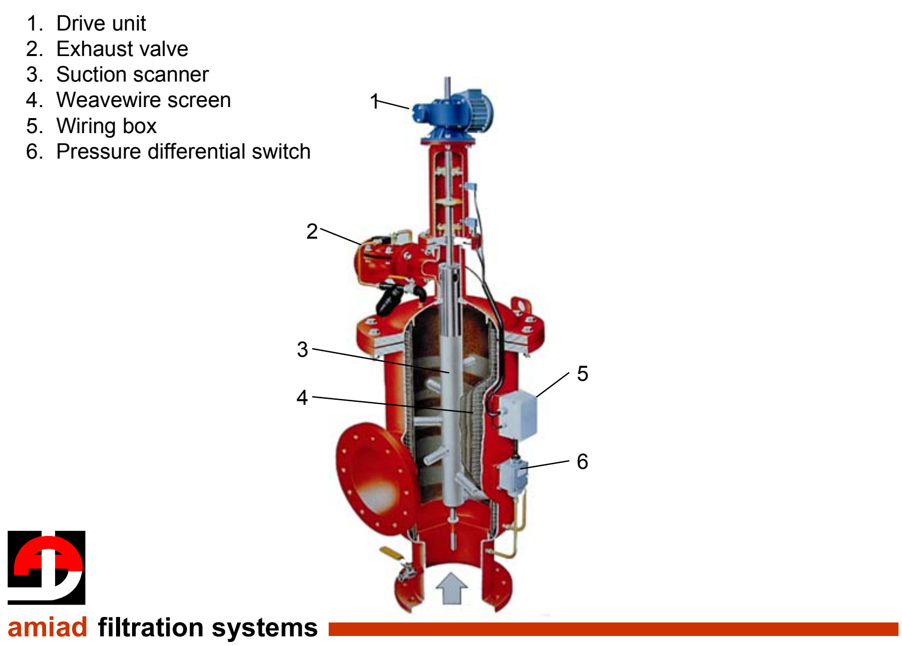

Figure 1: Amiad Model EBS Automatic Strainer

FILTER OPERATION

Unfiltered water flows into the filter through the inlet flange of the filter body. Water then proceeds through the cylindrical stainless steel filter element (screen) from the inside out causing particulates larger than the filtration degree of the screen to accumulate on the inside surface of the screen, progressively developing a filter cake. The filter cake, in turn, begins to trap particles much smaller than the openings in the screen. Effluent leaves the filter body through another flanged opening. An adjustable Pressure Differential Switch (PDS) continuously senses the pressure differential across the filter screen. The PDS signals the filter controller to initiate the cleaning cycle of the filter screen when the filter cake causes a pre-set pressure differential. The PDS has the capability of being adjusted to sense a pressure differential between 2 and 15 psi. A typical optimum setting for the PDS is 7 psi. During the cleaning cycle, there is no interruption of flow downstream of the filter. However, there could be a slight reduction in pressure or mildly reduced flow downstream depending upon system parameters such as pumps, valves, etc. Pressure loss through the entire filter containing a clean screen is less than 2 psi at maximum design flow rate and is usually less than 1 psi. This results in a total pressure drop across the filter remaining between 1 and 7 psi at all times. The filter operation and cleaning cycle is controlled and monitored by a Programmable Logic Control (PLC).

CLEANING MECHANISM

The filter screen cleaning mechanism is a suction scanner constructed of a 316 stainless steel assembly that rotates while also moving linearly. The suction scanner consist of a central tube with tubular nozzles equally spaced along the length of the central tube positioned perpendicular to the longitudinal axis of the central tube (see Fig. 1). A 3" flush valve connects the internal cavity of the suction scanner to atmospheric pressure outside the filter body. By opening the flush valve, the differential gauge pressure between the water inside the filter body (35-150 psig) and the atmosphere (0 psig) outside the filter body creates high suction forces at the openings of each of the suction scanner nozzles. This suction force causes water to flow backward through the screen in a small area at each nozzle pulling the filter cake off the screen and sucking it into the suction scanner and out the exhaust valve to waste. The driving mechanism then rotates the suction scanner at a slow, fixed rotation while simultaneously moving the scanner linearly at a fixed speed. The combination of rotation and linear movement gives each suction scanner nozzle a spiral path along the inside surface of the filter screen. The cleaning cycle is completed in 40 seconds or less, during which time the nozzles remove the filter cake from the entire filtration area of the filter screen.

DRIVE MECHANISM

A 1/2-hp electric gearhead motor drives the suction scanner. The connection between the motor and suction scanner assembly consists of a threaded shaft traveling inside a fixed threaded bearing. This arrangement gives the suction scanner its rotational and linear movements; thereby, giving the suction scanner nozzles a spiral motion along the inside of the filter screen. The suction scanner has a rotational speed of about 14-rpm and a linear speed of around 12-ipm at 440vac and 60hz. Two normally closed limit switches control the electric motor and all is monitored by the PLC.

FILTER SCREEN

The cylindrical filtration screen is constructed of four layers of 316L stainless steel components fabricated together forming a rigid unit to achieve both greater open area and mechanical strength. The screen's outer layer is constructed of a welded wedge-wire grid for mechanical strength. The fine weave-wire filtering media is sandwiched between two 3000-micron weave-wire layers to protect the fine screen from damage by large foreign objects and to prevent fatigue cracking of the fine wires. Heavy rings are positioned at each end to maintain the integrity of the screen's circular cross-section. Screen layers are bonded together at the structural ring around the circumference of each. The screen element is able to withstand an internal/external pressure differential of 250-psi without damage or distortion. Hydraulically inflated seals are located at each end of the screen element to prevent any influent leakage around the screen even at a differential pressure of over 250-psi.

WATER QUALITY PARAMETERS

SDI has been "empirically" correlated with the fouling tendency of some water treatment equipment such as R.O. devices. Therefore, it is only an "indicator" of the potential for membrane fouling. SDI calculations may vary as a function of water temperature making values obtained at different temperatures not necessarily comparable. Also, SDI values will vary with the membrane filter manufacturer used for the test. Thus, SDI values obtained with different filter manufacturers cannot be compared. (Ref. 6)

Correlation of turbidity with the mass or particle number concentration of suspended solids is difficult because the size, shape and refractive index of the particles affect the light-scattering properties of the suspension. (Ref. 5)

SDI and turbidity each have their place as a measurement of water quality. However, being indirect indicators neither has a positive correlation with the concentration of suspended solids in a water sample nor do they provide details regarding the number, size and distribution of particles in the water. This limits their use as tools to evaluate the efficiency and effectiveness of a self-cleaning pre-filter. (Ref. 7)

PRE-FILTRATION APPLICATIONS

One In August 1996, a sand media pre-filtration system was replaced at a coal fired utility plant near Las Vegas, NV with a self-cleaning mechanical screen filter. The utility had experienced too much sand carryover from the media filters. One-micron cartridge filters are located between the pre-filter and the R.O. membrane system. The flow rate is 250 gpm passing through the self-cleaning mechanical screen filter with a 10-micron screen. The raw water source is a well with a TSS concentration of 10.46 ppm. The filter effluent maintains TSS values of 2.5 ppm giving a TSS reduction of 76%. Laboratory studies have shown 99% removal of all particles over 5-micron in size and 86% removal of all 1-micron size particles. SDI values after the pre-filter have run consistently below 3.0. This self-cleaning mechanical screen pre-filter has been performed flawlessly for over 4 1/2 years. (Ref. 7)

Two A coal fired utility plant in eastern Wyoming receives water from a reservoir. Originally the water was passed through a bank of carbon media filters followed by 10-micron bag filters and 5-micron cartridge filters before reaching the R.O. membranes. The cartridge filters were plugging repeatedly with TSS passing through the media and bag filters and also with periodic episodes of carbon carryover from the media filters. In March 1998 a self-cleaning mechanical screen filter was installed with 10-micron screens to replace the 10-micron bag filters. A flow rate of 800 gpm passes through the system with a TSS concentration of 0.49 ppm delivered to the mechanical screen filter from the bank of carbon media filters. Effluent leaves the self-cleaning mechanical screen filter at 0.04 ppm for a TSS reduction of 92%. Carbon media upsets have had no effect on the R.O. membranes since installation of the mechanical screen filter. The nature of suspended solids in water from reservoirs differs from that in wells. Surface waters typically have a much higher concentration of organic matter that often leads to greater SDI values. SDI values after the mechanical pre-filter typically run 4.5-5.5. After three years of continuous operation, the self-cleaning mechanical screen pre-filter is still operating to the utility company's satisfaction. (Ref. 7)

Three A pilot test was set up at a utility plant in California in 1998 to test the TSS reduction by a self-cleaning mechanical screen filter on raw canal water. The San Joaquin River feeds the canal. The 10-micron filter received water from the canal with a TSS concentration of 2.51 ppm. The TSS concentration in the effluent from the filter was 0.08 ppm for a TSS reduction of 97%. (Ref. 7)

Four Recently a self-cleaning mechanical screen filter with a filtration degree of 10-micron was installed at an electronic firm in Kansas City, MO to replace dual media filters before an R.O. system. Water comes into the filters from the municipal supply system. The self-cleaning mechanical filter is producing water with SDI<3.0 meeting the customer's needs. (Ref. 7)

Five Well water is run through a self-cleaning mechanical screen filter with a 25-micron filtration degree at an electric utility in Tucson, AZ. This filter maintains a SDI<3 to the pleasure of the owner.

Six A glass manufacturing facility in Ontario, CAN was utilizing water from Lake Huron by passing it through a 5-micron cartridge before entering an R.O. system. The only pre-treatment before the cartridge was chlorination. The 5-micron cartridges not only plugged very quickly, but they did not provide enough protection to the R.O. membranes causing the membranes to need cleaning about three times more frequently than originally stated by the R.O system manufacturer. Two self-cleaning mechanical 10-micron screen filters were installed in parallel as pre-treatment to the cartridge filters. The cartridges were then changed from 5-micron to 1-micron. The mechanical filters have been performing for six months. Tests showed that in the particle size range of 15-30 microns, the 10-micron screen as expected removed all particles. In the 5-15 micron particle sizes, TSS was reduced by 63% from 0.56 ppm to 0.21 ppm. Even particles in the size range of 1-5 microns showed a TSS reduction of 36% as shown in Table 3.

Particle Size (microns)	Influent TSS (ppm)	Effluent TSS (ppm)	TSS Reduction
1-5	0.11	0.07	36%
5-15	0.56	0.21	63%
15-30	0.36	0	100%
1-30	1.03	0.28	73%

Table 3: Application Six Data

SUMMARY
Table 4 summarizes the data from the Applications given in this paper.

Application	Influent TSS (ppm)	Effluent TSS (ppm)	TSS Reduction	Effluent SDI
One	10.46	2.5	76%	<3.0
Two	0.49	0.04	92%	4.5
Three	2.51	0.08	97%	N/A
Four	N/A	N/A	N/A	<3.0
Five	N/A	N/A	N/A	<3
Six	1.03	0.28	73%	N/A

Table 4: Data Summary

Self-cleaning mechanical screen filters offer advantages over traditional multi media filters on several fronts:

- Capital costs are generally 30-60% lower for self-cleaning mechanical screen filters.
- Installation costs are much less for mechanical screen filters since no concrete pad is required and the piping itself usually supports the filter.
- Self-cleaning mechanical screen filters use 40-60% less water for cleaning than typical granular media filters.
- Energy requirements are reduced for self-cleaning mechanical screen filters that operate between 1-8 psi pressure loss across the filter compared to 6-12 psi pressure losses across a granular media filter.
- The cleaning cycle of a mechanical screen filter is usually <5% as long as that required by granular media filters for the same flow rate. This means less pressure and flow fluctuations downstream.
- Self-cleaning mechanical filters have no media to degrade or carryover.

Self-cleaning mechanical screen filters may or may not meet the SDI requirements for membrane system pre-filtration. This depends upon the physical parameters of the suspended solids in the feed water. However, self-cleaning mechanical screen filters can remove the solids down to less than 10-microns that tend to prematurely plug finer bag and cartridge filters. These finer filters will, in turn, provide water with acceptable SDI values. Self-cleaning mechanical screen filters make wise replacements for granular media filters. They also extend the life, performance and efficiency of fine bag or cartridge filters lowering capital and operational costs to membrane pre-filtration.

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