KEEP THE HORSE BEFORE THE CART: KEEP PRETREATMENT BEFORE THE MEMBRANE

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Abstract

Nearly all membrane systems, whether utilizing seawater, brackish water, river, lake, well, domestic secondary effluent, industrial secondary effluent, stormwater, industrial process water or any other raw water source, must utilize some form of pretreatment to remove unwanted organic and inorganic suspended solids. Bag and cartridge filters are efficient at removing suspended solids in all the aforementioned cases but must be replaced on a frequent and often costly basis. Some form of suspended solids removal system that cleans itself, maintains high flow rates and stays online at all times with a very low pressure drop would be ideal. That piece of equipment exists. This paper defines, explains and shows by example the versatility of automatic self-cleaning screen filters for removing up to 99% of all suspended solids from membrane influent allowing the fine cartridge filters, if even needed, to polish with very infrequent replacement. New screen filter technology makes possible the removal of all particles down to 10 microns without depending upon filter aids such as diatomaceous earth or self-forming filter cakes. This paper gives a full description of terms and their definitions related to automatic screen filters. A complete explanation of one manufacturer's self-cleaning filter operation is covered along with a number of real applications and laboratory analyses both before and after filters. An important aspect of this filter is that its cleaning cycle takes place without interrupting the filtration process. New materials are described for operation on deep sea drilling rigs under very difficult conditions. One application discussed is an automobile windshield manufacturer pretreating raw lake water with a 10-micron screen removing 77% of all suspended solids larger than 5 microns before R.O. membranes. Other case studies will show total suspended solids removal >97% relieving cartridge filters from overloading and allowing them to do a better job of membrane protection. Whether the reader's interests are desalination, reuse, drinking water treatment, wastewater treatment, industrial process water or any other membrane application, the filter described is of utmost interest because it *solves problems* encountered by all membrane users.

Terms and Definitions

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 described 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 municipal and industrial arenas, is an actual linear dimension of the *shortest* straight-line 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. The *absolute* filtration degree is the length of the *longest* straight-line distance across an individual opening of the filter medium.

Effective Filtration Area

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. Some filter manufactures will state "filtration area" meaning the entire surface area of the filter element regardless of flow blockages due to structural components.

Filtration Open Area

Another important definition needed when comparing filters and filtration methods is the *filtration open area*. This 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. Basic physics says that the pressure drop across a porous medium is proportional to the *square* of the velocity. For a given flow rate, less open area means higher velocity thus, a higher pressure drop. Screen filters, when clean, have enough open area to cause insignificant pressure drops across the screen. However, as dirt and debris begins to plug up openings in the screen, the open area that is available for the fixed flow rate to pass through is decreased leading to an ever increasing velocity through the screen. Since the pressure drop is proportional to the square of this velocity, the differential pressure across the screen will increase over time as an exponential function. This phenomenon is clearly shown in Figure 1. Less open area also means less dirt required to increase pressure drop across the screen element. The type of weave used to construct a filter screen can affect the open area greatly as shown in Table 1. Notice the relative consistency in open areas of weave-wire screens regardless of the filtration degree while wedge-wire screens show a sharp decrease in open areas as the filtration degree diminishes.

Water Quality

Water quality consists of a multitude of parameters, some relevant to filtration and many of no consequence. These parameters can be divided into two basic aspects, chemical and physical. Of most concern in filtration designs are the physical parameters of water quality.

Total Suspended Solids (TSS)

Particle load or *total suspended solids* (TSS) is of major concern in filtration and is best defined as the concentration of total solid particles above 0.45 microns given in milligrams per liter (mg/L) or parts per million (ppm). TSS alone offers limited help in the design of filtration systems with filtration degrees below 50 microns. The particle size distribution of the TSS is necessary for accurate fine filtration design.

Particle Size Distribution (PSD)

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 particle size unit, usually provided in one-micron increments. PSD can also be given in percent volume of TSS (volume density) per particle size unit. The latter means of expressing PSD is much more useful in designing fine screen filtration systems.

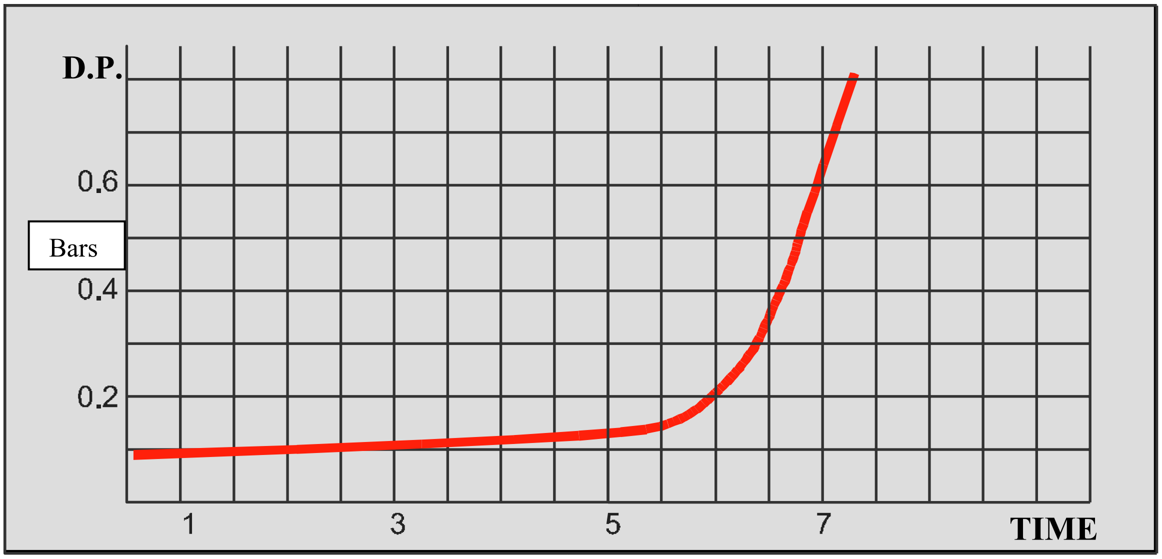

Figure 1. Time vs Differential Pressure (DP)

Table 1. Filtration Open Area

Filtration Degree	Filtration Open Area	
	Weave-Wire	Wedge-Wire
500 micron	37%	33%
300 micron	31%	23%
100 micron	32%	7%

Clogging Factors

Those elements that cause a filter or strainer to lose hydraulic capacity are referred to as *clogging factors* and can be divided into organic and inorganic segments. Organic clogging factors include all phyto-plankton such as algae and some bacteria, zooplankton like protozoa and small crustaceans, and animal and vegetal detritus. Typical inorganic factors include sand, silt, clay, metal shavings, pipe scale and rust flakes. The degree of difficulty for removing these clogging factors from a filter varies considerably, not only from factor to factor, but from filter medium to filter medium.

Case One

Historical Setting

Lake Forest is a small upper class community along the west shore of Lake Michigan about 35 miles north of downtown Chicago, IL. In 1890 a group of residents started the Lake Forest Water Company on the present site to provide water for the residents of the community. It remained a private utility for thirty years providing little or no real "treatment" of the water coming from Lake Michigan. In 1920 the city of Lake Forest bought the water utility naming it the Lake Forest Water Plant. There was a major building expansion on the site in 1928 with numerous building and infrastructure projects since that time. Two pipelines withdraw water from the lake. A 24" line runs out 2,975 feet from the shoreline while a 42" pipeline extends out about 3,900 feet. Both inlets vary in depth depending upon lake levels but are presently at about 25 feet below the surface. Lake surface elevations today are at near record low levels. Prior to the spring of 2004, the Lake Forest Water Plant provided traditional water treatment. Coagulating chemicals were added to the incoming water allowing flocculation to take place and then settlement in an appropriate basin. Next the water was run through gravity media filters with anthracite and sand. After chlorination the water was pumped to an elevated 1,500,000 gallon storage tank.

The Need for Change

Seven years ago the City of Lake Forest Water Plant reacted to a number of needs. The community was growing and capacity was becoming a problem with the existing equipment. The Environmental Protection Agency (EPA) changed its turbidity requirements from 0.5 NTU to 0.3 NTU and the city council was not certain that the antiquated equipment could perform. The cryptosporidium outbreak in Milwaukee, sending hundreds of thousands of residents to hospitals around the city, concerned the city council greatly feeling that there was always the possibility of that happening anywhere along the shores of Lake Michigan. In 1989 new filter bottoms were installed in the anthracite/sand filters of 1920s vintage. This repair convinced the city council that future retrofits of equipment this old was not prudent. An engineering firm was hired and the design of a totally new treatment facility was begun.

New Design

Initially the new design called for gutting the old system and installing brand new equipment using the same traditional processes. Half way through the design stage the Board realized that new guidelines and water quality requirements were sure to become effective in the future and though traditional water treatment processes could meet present requirements, they probably would fall short of any new more stringent requirements. New technologies were reviewed causing the core of the new treatment process to change to Ultrafiltration membranes. Design capacity is now 14 MGD and expandable in the future to 18 MGD if the need arises. Approximately 23,000 residents are served by the present Lake Forest Water Plant. The 24 hour/day operation is accomplished by four operators and five maintenance personnel all working 12 hour shifts. Water now comes directly to the plant without the addition of any coagulating chemicals. The process takes the raw water through 200 micron self-cleaning screen filters and then directly into the 0.01 micron Ultrafiltration membrane system. Reject from the membranes goes through flocculation and sedimentation with the addition of ferric sulfate to get the turbidity down to around 2 NTU. This water is then mixed with the raw incoming water to be recycled through the treatment process. Air integrity tests are conducted three times a day on the membranes producing 24,000 gallons of waste water per day. This water along with 16,000 gallons produced every 1½ days from the membrane backwashing process is sent to the city WWTP as the only wasted water leaving the Lake Forest Water Plant.

Pretreatment

Algae have traditionally been the biggest contaminant in the raw water of the Lake Forest Water Plant. In recent years zebra mussels (*Dreissena polymorpha)* have acted as filters for the entire lake transposing organic matter from the water column to the lake bottom. This has greatly decreased the turbidity and TSS in the raw water. However, algal blooms still occur and this algae must be removed before the membrane system. Four automatic self-cleaning screen filters were installed as the pretreatment system. They were equipped with 200-micron screens of 316L stainless steel weave-wire construction. Because surface water sources such as lakes, rivers, reservoirs and canals are dynamic, water quality can change dramatically. Future changes to the watershed such as land developments or changing farming practices can significantly alter the water quality in both still and moving water bodies. These watershed changes, more often than not, increase sediment runoff due to accelerated erosion. Not only does the inorganic TSS increase in the water body but nutrient runoff also accelerates adding to the organic TSS load and eventually leading to the overgrowth of organic matter causing the condition of eutrophication. Since the pretreatment system must handle present water quality conditions and anticipate possible future degraded conditions, the controls along with the inlet and outlet manifolds were designed for the future addition of a fifth filter body as shown in Figure 2. Each individual filter has its own manufacturer provided programmable logic controller (PLC) but these acted as slave controls to a master PLC that monitors and controls the entire water treatment process. Figure 3 depicts another view of the installation showing the slave controls for each filter. Each filter is made up of the components shown in Figure 4. Dirty water enters the inlet flange at the bottom of the strainer housing. The water passes into the cylindrical screen element made of 316L stainless steel, through the screen and out the side outlet flange. Suspended solid particles such as algae or sand are captured on the inside surface of the screen and build a filter cake. The open area of the screen decreases as this cake thickens causing the water velocity through the screen to increase thus, increasing the differential pressure across the screen element. A differential pressure switch (DPS) constantly compares the pressure inside and outside of the screen element. When a preset differential pressure threshold is reached (5 - 7 psi), the DPS signals the first slave PLC that it is time to begin a cleaning cycle. This slave PLC then signals the master PLC to first open the exhaust valve to atmospheric pressure. This valve is connected to the hollow 316 stainless steel suction scanner that has nozzles that end with a small opening within a few millimeters of the screen surface. The differential pressure at each nozzle hole, caused by the difference between the working gauge pressure (25 psi) and atmospheric gauge pressure (0 psi), results in a low-pressure area in the vicinity of each nozzle opening. The desired minimum pressure differential at the nozzle opening is 35 psi which is not available in this application. Therefore, a submerged centrifugal pump is located in the exhaust flush line to *pull* an additional negative 15 psi gauge pressure on the suction scanner. Thus, 25-(-15) = 40 psi differential at the nozzle opening. This pressure differential causes water to flow backward through the screen in this small area at a velocity of 30-50 ft/sec violently pulling the filter cake off the screen and sucking it into the suction scanner and out the exhaust valve to waste. While this is taking place, the PLC starts the electric drive unit that slowly rotates the suction scanner at 24 rpm. This slow rotation does not disturb the filter cake except where it is being sucked into the scanner at the nozzles. At the same time, the suction scanner is moved linearly by a threaded shaft passing through a fixed threaded bearing. This gives each suction scanner nozzle a spiral motion. When the upper limit switch is reached by an actuator on the drive shaft, signaling that every square inch of the screen has been covered by nozzles and that all debris has been cleaned from the screen surface, the PLC closes the exhaust valve and the drive unit reverses to move the scanner down to its starting position at the lower limit switch. The second filter will then go through the same cleaning cycle, then the third and the fourth all in sequence. At this point the system waits for the next threshold pressure differential across the screen to occur. The filtration process is never interrupted. A 120 minute timer function is also programmed into the master PLC to initiate a cleaning cycle at least every 120 minutes should a threshold pressure differential not occur within that time span. If one or more filters should be off-line for repairs or any other reason, the master PLC will skip those filters during the cleaning cycle and go to the next operating filter.

Figure 2

Figure 3

Data

Recent data from this sight shows great variability in raw water quality from day-to-day. This is portrayed in Table 2 along with TSS values "before" and "after" the automatic filters. Notice the apparent change in particle size distribution resulting in a wide swing in percent removal with a screen rated at a filtration degree of 200 microns.

Table 2. Water Quality Data

Date	TSS "Before" Filters (ppm)	TSS "After" Filters (ppm)	Removal (%)
5/19/04	206	76	63
5/20/04	<2	<2	--
5/21/04	12	1	92

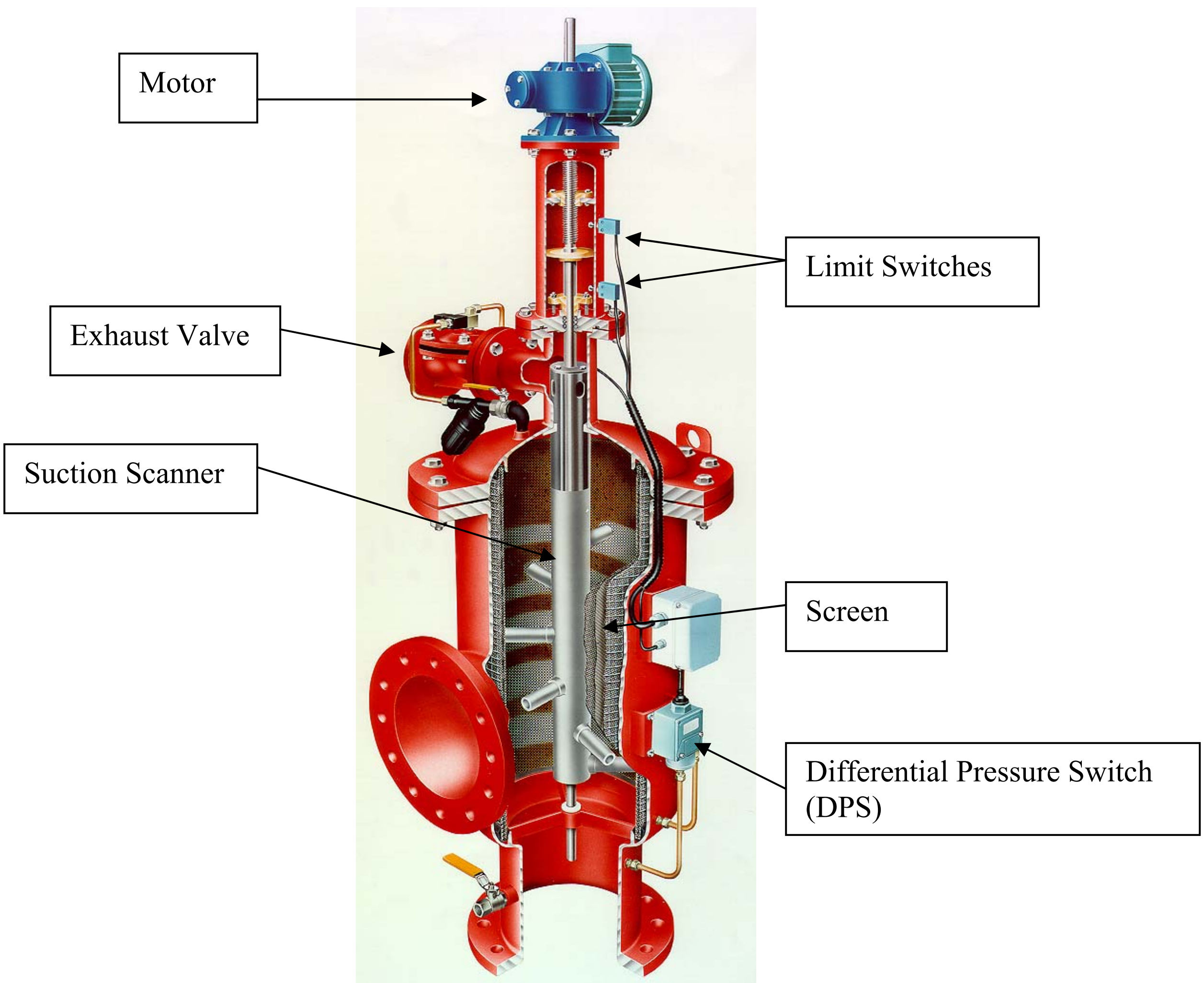

Figure 4

Case Two

A glass manufacturing facility in Ontario, Canada was utilizing water from Lake Huron by passing 450 gpm through 5-micron cartridges before entering an R.O. system. The only pre-treatment before the cartridges was chlorination. The 5-micron cartridges not only plugged very quickly (as often as every 20 minutes during storm events), 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 automatic self-cleaning 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 for better membrane protection. Tests results are self-explanatory as shown in Table 3.

Table 3. Water Quality Analyses Results

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%

Case Three

In August 1996, a sand media pre-filtration system was replaced at a coal fired utility plant near Las Vegas, NV with an automatic self-cleaning 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 automatic self-cleaning 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 total TSS reduction of 76%. Laboratory studies showed 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 automatic self-cleaning screen pre-filter has been performed flawlessly for eight years.

Materials of Construction

Standard filter units for fresh water use are constructed with housings made of 37-2 carbon steel either galvanized inside and out with the exterior protected with a polyester coating or simply coated with polyester both inside and out after proper shot blasting for surface preparation. The screen elements are made entirely of 316L stainless steel and the suction scanner assembly and drive shaft are 316 stainless steel. Standard seals are natural rubber.

Variations on the standard component materials include all 316 stainless steel housings and special seal materials such as EPDM, synthetic rubber or Teflon. For seawater applications, the housing can consist of a rubber lining bonded to 37-2 carbon steel or various ceramic coatings. Screen elements and suction scanners for brine, desalination, deep sea drilling rigs and other seawater applications are made from Monel or SMO 254.

Summary

Membrane technology has come a long way in the past few years. Their dependability as well as durability is increasing just as operating pressures are decreasing. New applications are appearing around the world and the technology will be heavily depended upon in the foreseeable future. With each application comes the need for pretreatment to remove organic and inorganic particles that can damage or at least compromise the membrane structure. Membranes can only perform to the degree that the pretreatment system performs. Therefore, the pretreatment system must function adequately and be reliable and robust. Automatic self-cleaning screen filters have proven their reliability and functionality as companions to membrane systems. With the ability to remove all or nearly all particles greater than 10 microns in size, these filters can stand alone as pretreatment for all but the finest R.O. membrane systems. And even R.O. systems need only add a fine polishing cartridge between the automatic self-cleaning screen filter and the membranes to form a complete functional and reliable water treatment system.

Acknowledgements

1. Bill Hensel, Chief Operator, Lake Forest Water Plant, Lake Forest, IL
2. Don Benedict, Technical Support Manager, Amiad Filtration Systems, Oxnard, CA
3. Tom Hamilton, President, Power Products, Battle Ground, WA

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