Microfiltration Performance Enhancement Using an Air-Scour, Air-Assisted Liquid Backwash Regime

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ABSTRACT

This paper presents recent advancements in the MEMCOR® membrane filtration process. The new CMF-L process incorporates an improved membrane technology with a low-pressure liquid backwash regime that uses less energy and increases water recovery. Suitable for new installations or retrofit of existing ones, this process reduces capital and operating costs of membrane filtration systems.

BACKGROUND

Filtration systems are essentially batch operations. The goal of system design and operation are to maintain the filtration process as long as possible before the system requires off-line cleaning. As the pore size of the filtration media decreases, the on-line time between cleanings generally increases. For example, a multi-media filter with relatively large "pores" is backwashed (cleaned) frequently. By contrast, a reverse osmosis (RO) system, with relatively small pores, undergoes cleaning infrequently. For membrane filtration systems, whether they be microfiltration (MF) or ultrafiltration (UF), the process of maintaining acceptable filtrate flow over a reasonable time is called flux enhancement. Any one or more of these techniques will reduce the frequency of costly chemical cleaning and downtime of the systems. Common flux enhancement techniques include backwash, maintenance wash, chemically enhanced backwash and relaxation.

The goal of backwashing is to physically remove suspended solids from the surface of the membrane, membrane pores and the membrane module itself. Backwashing may appear to be a relatively simple process; however, many factors can significantly impact the overall operation of the membrane system. Frequency and duration are two factors that will affect the mass balance, while the energy input during backwash can have a major effect on the operating costs.

Frequent backwashing will indeed keep the filtrate flow rates high, but the reduction in on-line time, mechanical component wear, and the larger quantity of wastewater created will have a negative overall effect. Since most membrane filtration systems use filtrate as the source of backwash water, frequent backwashing also consumes large amounts of filtrate. The backwash frequency optimized during pilot studies or during the first few months of operation determines the balance between the filtrate flow rate, backwash interval, and the off-line time for chemical cleaning.

Backwash duration is another key factor in the process. The goal is to keep the duration short enough to minimize the off-line time and wastewater generated, and to conserve the filtrate used for the backwash process. However, sufficient volume is required to remove the suspended solids from the membrane and membrane module. If not completely removed from the system, the suspended solids will re-accumulate on the surface of the membrane.

Lastly, backwashing does not come for free, as it uses energy. Whether the energy is in the form of air pressure or pump pressure, or both, water still needs to be moved backwards through the membrane and flushed from the membrane module.

HISTORICAL DEVELOPMENTS

Early MF and UF systems used a simple backwards flow of filtrate to accomplish the backwash. Filtrate was stored and a separate pump was used to deliver this filtrate backwards through the membrane, dislodging the accumulated suspended solids and displacing them from the system. Some membrane systems also employed a “fast flush” that reduced the backpressure on the feed side, to improve the efficiency of the backwash process and reduce the energy requirement.

In the mid 1980’s, compressed air was used instead of filtrate to dislodge the suspended solids from the membrane. Feedwater, instead of filtrate, was used to displace the released suspended solids from the membrane system. This was a major advancement in the backwash process, which maintained high filtrate flow rates and extended the time between off-line cleanings. However, by today’s standards, the process consumed more energy and generated more wastewater than desired.

Over the years, other flux enhancement techniques have been developed to create a favorable balance between on-line time, energy consumption and wastewater generation. Some of these techniques use dilute chemicals, such as chlorine, during the backwash steps, which are commonly referred to as “maintenance washes” or “chemically enhanced backwashes”. Their goal is to reduce the frequency of a full (off-line) chemical cleaning. While longer in duration than a normal backwash, they are much shorter than a full off-line cleaning and generate less wastewater.

THE NEW CMF-L PROCESS

The newly developed backwash process employs low-pressure air scouring and an air assisted filtrate backwash. In combination, these two features reduce the wastewater generated, eliminate the requirement for backwash pump and backwash water storage and reduce the energy needed to conduct the backwash. This process is applicable to hollow fiber membrane systems whose service flow is from the outside of the fibers to the inside of the fibers.

Removal of accumulated suspended solids from the membrane surface is accomplished by two methods. Low-pressure air, introduced on the outside of the hollow fiber bundle, aggressively scours the membrane surface, loosening and dislodging the suspended solids. The small amount of filtrate contained in the fiber lumen and in the filtrate manifold is pushed backwards through the membrane using 30-psig of air as the driving force rather than a pump. This liquid backwash assists in further dislodging the solids within the membrane pores. Once the suspended solids are released from the surface of the membrane, they are removed from the membrane module (and system) through a purge step. To improve the overall recovery of the membrane filtration system, the purge step uses low-pressure air instead of water to displace the remaining water, laden with suspended solids, from the system. The new backwash process is summarized in Table 1 below. Table 2 compares the previous backwash process to the new one, and shows the significant improvements in energy usage, waste volumes and recovery of filtrate from raw water.

Table 1: CMF-L Backwash Process (values stated per 252 ft^2 membrane module)

1. Filter Down	Reduces shell side volume, recovers filtrate Displace shell side feed w/air	1.6 gal filtrate collected 0.6 SCF @ 30 psig 10 - 30 seconds
2. Aeration & Backwash	Loosens solids on membrane Removes solids from membrane Air on shell side and filtrate side	3.8 SCFM scour rate @ 5-8 psig 2.4 SCFM @ 30 psig air-assisted liquid backwash 15 - 30 Seconds
3. Post Aeration	Continues to loosen solids Air on shell side from bottom	No waste 3.8 SCFM scour rate 15 seconds
4. Drain Down	Purges solids from module Air purge on shell side from top	0.88 SCFM @ 30 psig 10 – 20 seconds
5. Shell Fill	Purges air from module Feedwater fill from bottom	20 – 25 seconds
6. Optional Sweep	Flushes concentrated waste from module (Used on high NTU waters) Feed water flushes to drain	0.8 – 1.4 gallons waste 10 seconds
7. Lumen Fill	Purges air from lumens and rinse Feedwater fill from bottom	20 seconds
Totals		5.0 - 8.3 gallons wastewater 3.8 SCF air @ STP 90 - 150 seconds (120 average)

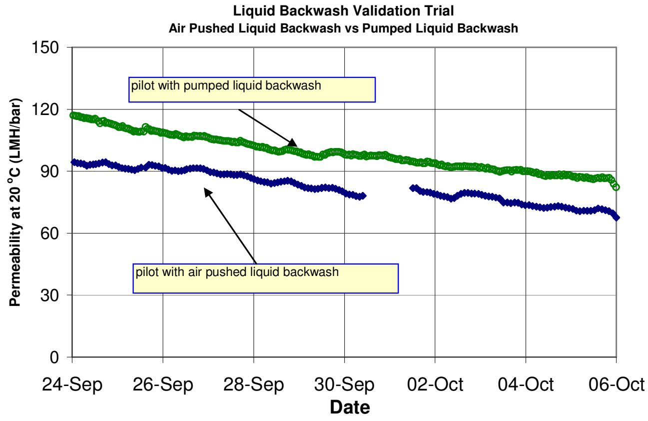
Table 2: Comparison of Backwash Processes (values stated per membrane module)

System Parameter	Previous	CMF-L	Reduction
Backwash Pressure (psig)	90	30	66%
Waste Volume High NTU Feed (gallons)	20	8.3	58%
Waste Volume Low NTU Feed (gallons)	20	5.0	75%
Air Consumption (ft^3 at STP)	7.0	3.8	45%
Cycle Length (seconds)	~180	~120	33%
Water Recovery	91%	96+%	5% increase

Before commercializing the new process, extensive R&D studies were carried out to validate the concept and determine the target operating conditions. Normalized data such as membrane permeability (liters/m^2/hr/bar) were calculated and plotted over time to determine the effectiveness of each validation step.

The first validation protocol proved that driving the hold-up volume of filtrate backwards through the membrane with air would provide sufficient force and volume as compared to pumping filtrate backwards through the membrane which is shown in Figure 1.

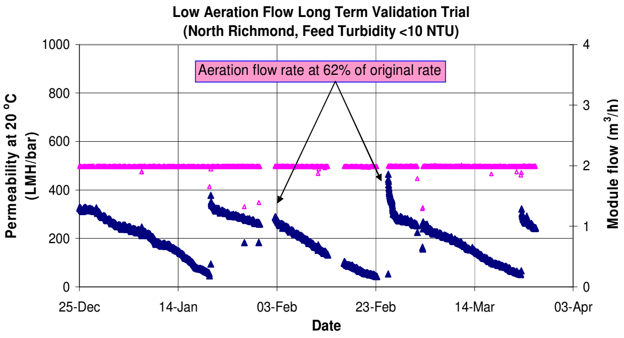
Fig. 1: Validation of Air-Assisted Liquid Backwash



The top curve in Figure 1 indicates the permeability of a new membrane operated with a pumped backwash. The bottom curve in Figure 1 indicates the permeability of an older membrane operated with the air-assisted liquid backwash. The lower permeability of the second membrane is within expected performance based on the previous use of that membrane during the study. However, the decline in permeability of both membranes is parallel, which demonstrated the effectiveness of the air-assisted liquid backwash to be equal to that of a pumped backwash.

The second validation protocol determined the optimum air-scour rate. As would be expected, the effectiveness of flux restoration reached a point of diminishing returns as the air-scour rate was increased. Originally, the air-scour rate was set at 6 SCFM per module and subsequently reduced over time to determine the affects on permeability. Figure 2 shows the reduced air-scour rate (from 6 SCFM to 3.8 SCFM) had no impact on the permeability characteristics of the membrane while maintaining a constant flux of 2 m^3/hr (top line in graph). It was also determined that air-scour rates below 3.8 SCFM lead to a higher rate of permeability decline.

Fig. 2: Validation of Air-Scour Rates



REAL LIFE EXAMPLE

Although commercial installations of the CMF-L process have shown that they meet or exceed all expectations, the most interesting case is one where the new process replaced an older technology to provide a true comparison. The first retrofit plant of this technology at Pottawatomie County, Oklahoma, USA in the spring of 2004 demonstrated that the new process exceeded design requirements. The new membrane filtration system was able to meet the water demand even when the feed turbidity was higher than 100 NTU. The mass balance in Table 3 details the consumption of feedwater, production of filtrate and generation of wastewater. With these volumes totaled and reported as a percent recovery, it is evident that the new backwash process made significant improvements in this area.

Table 3: Mass Balance

Daily Values	Previous	CMF-L
A. Raw Water Input (gallons)	329,670	312,500
B. Net Filtrate (gallons)	300,000	300,00
C. Wastewater (gallons)	29,670	12,500
D. Gallons Wastewater / 1000 gallons Filtrate	98.9	41.7
E. Recovery [B / A]	91%	96%

In addition to the water savings shown above, the new membranes operate at approximately one-half of the pressure than the previous membranes. This is due partially to the membranes being new, but more so due to the higher permeability characteristics of the new membranes. The total energy savings realized in this retrofit is 40%.

PAPER STUDY

The example above shows the operational improvements realized when retrofitting an older membrane filtration system with the new CMF-L process. The same benefits apply to a new membrane filtration system with the additional benefit of a lower installed cost. The example below evaluates membrane filtration designs and costs using previous state-of-the-art technology and the new CMF-L technology. For this study, a drinking water plant with a capacity of 7.4 MGD treating surface water with an average turbidity of 8 NTU was selected, and also included a separate backwash recovery system capable of recovering up to 90% of the backwash waste from the primary system.

The major equipment, detailed in Table 4, shows the differences in design between the two technologies. Of particular importance is the substantially reduced size of the backwash recovery system. Due to the higher recovery of the primary system that uses the CMF-L process, the amount of backwash water to recover is much lower than with previous technology. The new backwash recovery system is roughly one-third the size of the previous backwash recovery system.

Table 4: Major Equipment Summary

7.4 MGD Plant	Previous	CMF-L
Primary Systems (modules)	(6) 112	(6) 108
Recovery Systems (modules)	(2) 48	(2) 18
Backwash Equipment		
Pumps (gpm)	(2) 273	Not Required
Forwarding Tank (gal)	5280	Not Required
Receiving Tank (gal)	5280	1320
Compressors (CFM)	(2) 114	(2) 55
Blowers (CFM)	Not Req'd	(1) 630
Air Receivers (gallons)	(2) 1850	(1) 1060 (1) 240

Other notable differences are the backwash pumping and storage requirements. The previous technology required a high volume of feedwater to flush the membrane system after the air backwash, thus a separate backwash forwarding tank and backwash pumps were required to conduct this step. During the air backwash step of the previous technology, a large volume of high-pressure water required collection in a specially designed tank that would dissipate the energy. Since the new CMF-L process uses low-pressure air to drive filtrate backwards through the membranes, it eliminates the requirements for a backwash forwarding tank and pump. Collection of the backwash water is still required before re-processing or discharge with the new system; however, the collection tank is simply an off-the-shelf design.

Lastly, the reduced air compressor requirements are readily apparent. For the process air, the new technology requires one-half the volume at one-third the pressure. Control air is roughly the same for both technologies and is a negligible amount for either.

Table 5 summarizes the capital and operating cost estimates for the membrane filtration systems, ancillary equipment (pumps, tanks, and air systems), controls and installation based on the process designs above.

Table 5: Economic Summary

7.4 MGD Plant	Previous	CMF-L	Savings
Complete System Installed Cost	$4,247,000	$3,789,000	11%
Annual Operating Cost (electrical only)	$29,700	$17,800	40%

CONCLUSIONS

Recent advancements in membranes and backwash processes have shown to reduce the total costs of membrane filtration systems. The advancements described in this paper, which incorporate improved membrane technology with a new low-pressure liquid backwash regime, use less energy and increases water recovery. These advancements are beneficial for new installations or retrofit of existing ones.

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