Reclamation of Sand Filter Backwash Effluent using HYDRAcap LD Capillary UF Membrane Technology

By

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Introduction

The conventional treatment of surface water for potable application may include a number of treatment steps. The most common approach includes sedimentation followed by coagulation and media filtration. Operation of such systems generates a discharge stream, which mainly includes backwash water from the media filters. The discharged volume represents only about 2% - 5% of the treated flow. The backwash stream contains suspended materials that were removed from the treated water and flocculant chemicals. It also may contain a high concentration of pathogens that were originally present in the surface water. Discharging such a stream to the environment can represent a problem, especially in large filtration systems. Novel, backwashable, membrane capillary ultrafiltration technology by Hydranautics is now being applied specifically for backwash treatment of conventional filtration discharge streams. The HYDRAcap capillary technology has a very high rate of pathogen rejection, and at the same time, has the capability to reclaim some of the backwash water and reduce the discharge volume down to 15% of the initial backwash stream. This paper will describe the design and operational results of the UF capillary system treating sand filter effluents. Evaluation of the economics of the integration of conventional filtration with backwashable UF capillary technology will be presented as well.

HYDRAcap Membrane Technology

Hydranautics manufactures the HYDRAcap capillary ultrafiltration membrane technology in both 0.8 mm and 1.2 mm O.D. Molecular weight cut-off of the HYDRAcap capillary membrane is 100,000-150,000 Daltons. A 225 mm diameter HYDRAcap module (Fig. 1) contains about 13,000 fibers of 0.8 mm ID. The fiber polymer is polyethersulfone, modified to maintain a hydrophilic property. The flow pattern is inside out (feed water enters bore of the capillary). New capillary ultrafiltration technology offered recently is based on a large diameter capillary membrane fiber configuration. The capillary inside diameter (I.D.) is 1.2 mm and outside diameter (O.D.) is 2.0 mm. This product is designated HYDRAcap LD.

Two common innovative properties of the new commercial capillary technology include:

1. Frequent, short duration, automatically sequenced flushing (or backflushing in some models) of the capillary fibers, enables to maintain stable permeate flux rates with little off-line time.
2. Ability to operate at a very low cross flow velocity, or even in direct filtration mode.

The operation sequence consists of a forward filtration step (10 – 30 min), followed by a forward flush (5 – 10 sec), followed by a filtrate backwash (20 – 60 sec).

During the backwash step the foulant layer is lifted from the capillary membrane surface and flushed out from the capillaries. The frequent pulse cleaning results in stable permeate flux rates. During the forward filtration step the feed pressure is in the range of 0.3 to 1.5 bar (4 – 22 psi).

Figure 1: HYDRAcap Module

Ultrafiltration membranes such as HYDRAcap are designed for particulate removal. Water is pressurized through the membrane and particulates are left at the membrane surface. Due to the small pore size of the membrane, effectively all suspended solids including microorganisms are rejected. These particulates build up in concentration at the membrane surface, thus the water flow direction is periodically reversed to remove particulate matter (backwash). The representative removal capability of the capillary module is summarized in Table 1.

Table 1. Removal capability of the HYDRAcap capillary technology

Constituent	**Removal rate**
Particles > 2 um	2.5 – 3.5 log
SDI	Filtrate 1.0 – 2.5***
Virus	> 4 log*
Giardia	> 4 log*
Cryptosporidium	> 4 log*
Turbidity	Filtrate < 0.1 NTU**
TOC reduction	0 – 25 %
TOC reduction with coagulant	25 – 50 %

* California DHS Certification
** Tested on feed NTU up to 50
*** Dependent upon feed water characteristics

Membrane and process specifications for the HYDRAcap module is provided in Table 2.

Table 2. HYDRAcap - Membrane and process parameters

Configuration	Capillary
Membrane polymer	Hydrophilic polyether sulfone
MWCO	100,000 – 150,000
Nominal membrane area HYDRAcap HYDRAcap LD	 40" 30 m2 (320 ft^2), 60" 46 m2 (500 ft^2) 40" 19 m^2 (210 ft^2), 60" 30 m^2 (320 ft^2)
Capillary ID/OD HYDRAcap HYDRAcap LD	 0.8 mm/1.3 mm 1.2 mm/2.0 mm
Application data	
Prefitration requirement	150 micron
Typical filtration flux range	59 -145 l/m2-h (35-85 gfd)
ph range	2 – 13
Continuous free chlorine tolerance	100 ppm
Instantaneous free chlorine tolerance	200 ppm
Operation mode	Cross flow or direct flow, backwashable
Maximum pressure	5 bar (73 psi)
Maximum operating temperature	40 C (104 F)
Transmebrane pressure range at 20 C	0.3 – 1.5 bar (4-22 psi)
Maximum TMP	2 bar (29 psi)

Typical process conditions	
Backwash pressure	2.4 bar (35 psi)
Backwash flux	298- 340 l/m2-hr (175-200 gfd)
Backwash frequency	Once every 15 – 60 min
Backwash duration	30 – 60 sec
Cleaning frequency	Once every 1 – 2 months
Cleaning solutions	NaOCl + NaOH, Citric acid
Materials of construction	
Fibers	Polyethersulfone
Potting material	Epoxy
Fiber bundle netting/spacer	Polypropylene
Vessel end cap	Glass-filled polypropylene
Vessel shell and core tube	PVC

The HYDRAcap elements are connected together in a parallel array of HYDRABLOC™ skids (Fig 2). Each HYDRABLOC will process water, backwash, and undergo an integrity test as a single entity. Each HYDRABLOC contains HYDRAcap UF modules, automatic valves, instrumentation, structural supports and piping manifolds. A typical HYDRABLOC can contain from 8 to 216 HYDRAcap modules with nominal filtrate capacity of 400 to 16,000 m3/day (100,000 gpd – 4,200,000 gpd). The major area of application for this technology is in the production of potable water, providing a barrier against water born pathogens. Additional applications include treatment of municipal and industrial wastewater. Reclamation of media filter backwash effluent is an emerging application mainly driven by new regulations.

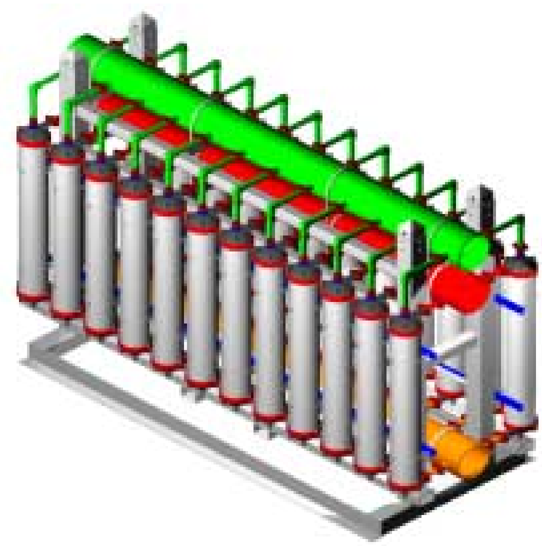

Figure 2: 24 Module HYDRABLOC™ Design

Filter backwash water recovery

Operation of media filters produces backwash water, which represents 2 – 5% of the total water processed. In the past, backwash water has been discharged to a surface water body or to a sedimentation lagoon. This type of disposal is simple and relatively inexpensive. The backwash water can be reclaimed to improve water conservation. In some plants the backwash water is being returned directly, after initial separation of solids, to the intake of the treatment facility. However, because the backwash water is generated in slugs, an equalization tank or reservoir is required. The conventional equipment, used for reclamation of backwash water, may include sedimentation tanks, thickeners and pressure dewatering equipment. In the US, recent EPA regulations make it mandatory that all backwash water be reclaimed and returned upstream of the water treatment system. The Filter Backwash Recycling Rule will apply to more than 4600 systems, serving nearly 35 million customers in the US.

Use of conventional technology to process backwash water may represent a problem in systems processing surface water for potable applications. The backwash water may contain high concentration of bacteria, giardia cysts and cryptosporidium oocysts. Conventional water treatment technology does not provide consistent removal level of pathogens. Ultrafiltration membrane capillary technology is more reliable in removing all suspended matter, including colloidal particles and pathogens. The capillary membrane provides a definite separation barrier, the integrity of which can be conveniently tested. However, even after the sedimentation step, the backwash stream still contains a high concentration of suspended solids (about 10 mg/l) that can easily plug the regular capillary bore of 0.8 mm ID. Therefore, for the backwash water recovery application a larger ID diameter fiber is required. Even with larger diameter fibers, process parameters need to be optimized to prevent solids accumulation in the module.

Capillary element configuration for backwash recovery

Field experience indicates that, for backwash water recovery applications, larger ID capillary fibers are required, as compared to the conventional 0.8 mm, to prevent plugging of the fiber bore. A 50% larger ID of 1.2 mm is sufficient to prevent fiber blockage by suspended matter encountered in filter backwash effluent. Due to the larger capillary diameter, the module contains only 5600 fibers, which provides 19 m^2 (210 ft^2) of membrane area for a 1m (40") long shell. For comparison, a module with standard 0.8 mm fibers contains about 13,000 fibers and 30 m^2 (500 ft^2) of membrane area for a module of the same length. Except for the fiber diameter and total membrane area, the module with large diameter capillaries has the same configuration as the one with 0.8 ID mm fibers. The flow configuration is also inside out, feed flows inside the capillary bore. The advantage of inside-out configuration is that the feed flow follows a straight path, eliminating stagnant areas and the possibility of accumulating solids inside the module.

Operating parameters

A pilot unit, equipped with the HYDRAcap LD (1.2 mm ID fibers) module, was operated for the treatment of filter backwash effluent. The objective of the study was to optimize process parameters for a design of a full-scale commercial system at this location. The unit was treating supernatant from a continuous thickener. The thickener was receiving backwash water from a commercial filtration system processing surface water for potable use. The module operated at a filtrate flux rate range of 80 – 100 l/m2-hr (44-55 gfd). The time between backwash cycles was 20 min. The backwash operation was initiated with a 5 sec forward flush at a flow rate of 7.5 m^3/hr (33 gpm). This was followed by 10 sec backwash flow from the top end of the module at the flux rate of 395 l/m2-hr (219 gfd). It was followed by a 10 sec backwash flow from the bottom end at the same flux rate. The effect of backwash sequence on the capillary membrane permeability is shown in Fig 4. Four times a day the backwash was followed by a 5-minute soak time with permeate containing 10 ppm of NaOCl. A caustic cleaning with 0.03 M NaOH was conducted 1 – 2 times a week. Backwash volume was 7 – 8% of feed flow and the recovery rate was close to 90%, including forward flush step.

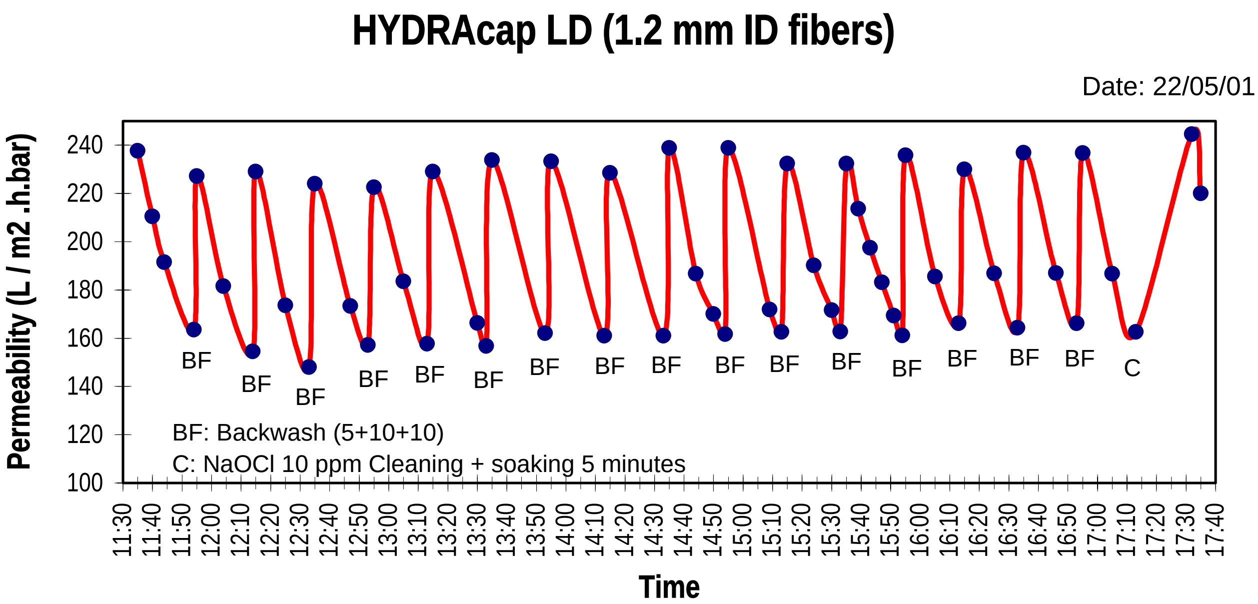

Figure 4: Backwash sequence during pilot test

Results and Discussion

Figure 5 illustrates the Flux and TMP profile of a module with 1.2 mm ID fibers operating for five weeks (16th May to 21st June). System operational data was taken approximately every four hours. These values correspond to the instant just after backwash. Performance was very stable over this period, with a permeability around 240 L/m^{2}h-bar (141 gfd-psi) after backwash dropping to approximately 140 L/m^{2}h-bar (82 gfd-psi) just before backwash.

An initial trial period with a module containing 0.8 mm fibers showed that it was not possible to maintain permeability without using a full chemical cleaning procedure every few cycles. It appeared that the backwash process was not capable of removing accumulated solids effectively from the inside of the fibers, resulting in a progressive loss of permeability in successive cycles.

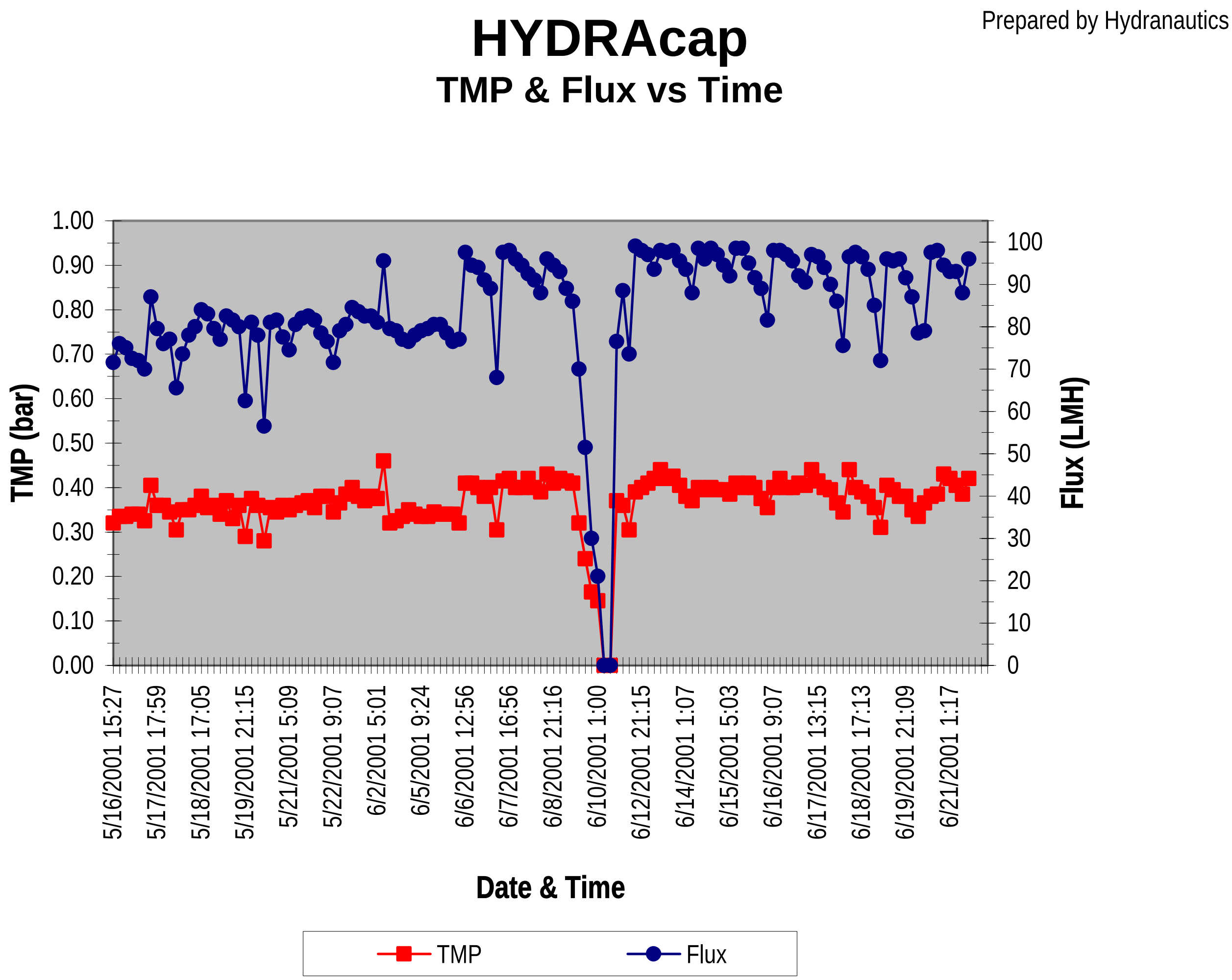

Figure 5: HYDRAcap TMP & Flux vs. Time

Table 3 shows a summary of feed and filtrate quality for the trial with the 1.2 mm fiber module. The results indicate very good reduction of turbidity and coliform bacteria. As can be expected no significant reduction of color was achieved. As the graph shows, occasionally the permeability declined, especially during the night and weekends, due to the fouling of the strainer. However, after manual cleaning of the strainer, the flux always returned to its original value, throughout the period of the trial. In addition, as Figure 5 indicates, the plant shut down on the 10th and 11th of June. This was also due to the high fouling of the strainer, which resulted in the permeate tank drawing emptying. Strainer plugging was the result of the low permeate flow during operation, not producing the required amount of water to carry out the backwashes. Once again, after a proper cleaning of the strainer, the permeability returned to its normal value.

Table 3. Summary of feed and filtrate quality results.

	Average	Minimum	Maximum
Feed turbidity	2.08	0.97	4.50
Filtrate turbidity	0.12	0.05	0.26
Feed fecal coli.	1.48	0.00	10.20
Filtrate fecal coli.	0.00	0.00	0.00
Feed color (Hazen)	8.12	6.25	10.50
Filtr. color (Hazen)	7.36	4.20	10.00

UF system design

The commercial system design, based on the results of the pilot unit operation, will utilize capillary UF HYDRAcap-LD membrane modules mounted vertically in a parallel array. The capillary fibers are of 1.2 mm ID, 2.0 mm OD. The membrane polymer is hydrophilic polyethersulfone developed to minimize fouling by water-born organic constituents. The plant will be designed to operate at a flux rate of 80 l/m2-hr (47 gfd) with a 20 min operation sequence, between backwashing.

Cost

The ultrafiltration system for reclamation of filter media backwash effluent will be more expensive than a UF system designed for the treatment of surface water. The higher cost is a result of operating the capillary membranes at a lower flux rate: 80 l/m^2-hr (47 gfd) as compared to 100 l/m^2-hr (59 gfd). Also, the membrane modules used for backwash recovery have about 63% of the membrane area of the standard module. Therefore, for a given filtrate capacity, the backwash recovery system will consist of approximately twice the number of membrane modules than the one used for surface water treatment. Accordingly, the equipment cost and the operating cost of backwash recovery equipment will be higher. Using as a reference the published results of a tender for a 20,000 m^3/day (5.3 MGD) capillary system for treating surface water, the equipment cost of a backwash recovery system is estimated to be about $200/m3-day ($0.76/gal-day). The water cost components are listed in Table 4.

Table 4. Estimated cost components for backwash recovery system

Equipment cost, $/m3-day ($/gal-day)	150.0 - 200.0 (0.57-0.76)
Capital cost @ 6% interest rate, $/m3 ($/1000 gal)	0.030 - 0.040 (0.11-0.15)
Power, $/m3 ($/1000 gal)	0.005 - 0.007 (0.02-0.03)
Chemicals, $/m3 ($/1000 gal)	0.004 - 0.006 (0.015-0.023)
Membrane replacement, $/m3 ($/1000 gal)	0.030 - 0.034 (0.11-0.13)
Total water cost, $/m3 ($/1000 gal)	0.069 - 0.087 (0.26-0.33)

Conclusion

- For the application of capillary filtration of the effluent from the thickener, use of fibers with 0.8 mm ID is not recommended due to the low backwash efficiency.
- However, performance of the module with the HYDRAcap LD (1.2 mm ID fibers) on the waste stream from the thickener was excellent with a stable TMP of 0.35 - 0.40 bar (5-6 psi) at a flux of 80-100 L/h-m^2 (47 – 59 gfd).
- Backwash volumes were 7-8% of forward flow, and the recovery of the plant was close to 90%, including forward flush.
- Filtrate quality was excellent (see Table 3).
- For a full-scale plant design, the plant sizing would be based on 80 L/h.m^2 (47 gfd), with a 20 minutes run time between back flush cycles.
- Disinfection with 10 ppm NaOCl is required 4 times a day.
- Chemical cleaning with 0.03M NaOH is required 1-2 times a week.
- An automatic self-cleaning strainer is recommended for this application.