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HYDRAcap® MAX: innovative micro-filtration for reverse osmosis pretreatment and water reuse

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ABSTRACT

Hydranautics has been a manufacturer of organic membranes for more than 30 years and has always been a technology leader. Being part of the Nitto Denko Group since 1987, hydranautics has inherited Nitto Denko's innovative philosophy. In September 2011, hydranautics announced the commercialization of its new PVDF hollow fiber microfiltration module: HYDRAcap® MAX. This new out/in module features one of the highest membrane areas currently available in the industry. Furthermore, HYDRAcap® MAX offers an air scour (AS) mode that allows the designer to eliminate the backwash sequence and pump; this results in increased recovery and lower capital expenses. The key applications for HYDRAcap® MAX are reverse osmosis pretreatment and water reuse, for both industrial and municipal applications from various types of water sources.This study will introduce HYDRAcap® MAX technology and its advantages, including higher membrane area resulting in lower footprint and innovative design resulting in optimized recovery. It will also discuss the operating sequences (i.e. filtration, AS, and cleanings), provide data from a case study, and give an example of a medium size system.

Keywords: MF; Footprint; Air scour; Recovery; IMS

1. Introduction

Hydranautics has been a manufacturer of organic membranes for more than 30 years and has always been a technology leader. Being part of the Nitto Denko Group since 1987, hydranautics has inherited Nitto Denko's innovative philosophy. In September 2011, hydranautics announced the commercialization of its new PVDF hollow fiber microfiltration (MF) module: HYDRAcap® MAX. This new out/in module features one of the highest membrane areas currently available in the industry. Furthermore, HYDRAcap® MAX offers an air scour (AS) mode that allows the designer to eliminate the backwash sequence and pump; this results in increased recovery and lower capital expenses. The key applications for HYDRAcap® MAX are reverse osmosis (RO) pretreatment and water reuse, for both industrial, and municipal applications from various types of water sources.

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This study will introduce HYDRAcap® MAX technology and its advantages, including higher membrane area resulting in lower footprint and innovative design resulting in optimized recovery. It will also discuss the operating sequences (i.e. filtration, AS, and cleanings), provide data from a case study, and give an example of a medium size system.

2. Hydracap® max design

The HYDRAcap® MAX module is a vertically oriented, pressurized MF module using PVDF fibers, which operates in outside to inside filtration mode. The PVDF hollow fibers used in the module are produced using a thermally induced phase separation (TIPS) process in order to create a highly crystalline structure, which provides greater physical strength (see Fig. 1) and chemical resistance (see Table 1). The tensile strength and burst pressure of the membrane are three times higher than conventional PVDF fibers.

It is produced in three sizes: HYDRAcap® MAX 40 (40 inches long with 51 m^2 of active membrane area), HYDRAcap® MAX 60 (60 inches long with 78 m^2 of active membrane area), and HYDRAcap® MAX 80 (80 inches long with 105 m^2 of active membrane area). The modules are designed in such a way that allows them to be used as single units or connected in parallel as multiple module units. The main physical and chemical characteristics are listed in the tables in Fig. 2 and Table 1.

3. Hydracap® max advantages

On top of the improved fiber technology, HYDRAcap® MAX has many other key advantages. The first advantage is the high membrane area per module. Using a 10″ shell, ~14,600 fibers makes up one module, which reduces the total number of modules required per rack. This also further reduces the size and footprint of racks as well as the number of connections per rack.

Table 1
HYDRAcap® MAX chemical characteristics and operating parameters

	Operating range
Filtrate flux, gfd ($l/m^2/hr$)	20–65 (34–110)
Filtrate flow, gpm (m^3/h)	
HYDRAcap® MAX 60	11.7–37.9 (2.7–8.6)
HYDRAcap® MAX 80	15.7–51.0 (3.6–11.6)
Air scour flowrate, acfm (m^3/hr)	7.3–9.1 (12.3–15.1)
Operating pH	4–10
Cleaning pH	1–13
Maximum instantaneous chlorine tolerance, ppm	5,000
Total chlorine tolerance, ppm-h	>750,000
Maximum feed pressure, psig (bar)	73(5)
Transmembrane pressure (TMP), psig (bar)	1–30 (0.07–2.0)

Another advantage is the design. The out/in design allows for operational flexibility, which provides the ability to treat feed waters with turbidity as high as 300 NTU. Furthermore, the fibers are fixed inside of the shell at each end using a hard epoxy potting and then layered with a soft potting material to act as a shock absorber minimizing fiber breakage during operation.

Lastly, one of the key advantages of HYDRAcap® MAX is its cleaning regime as it does not use backwash, but rather AS, thus removing the need for a backwash pump and extensive backwash flows. This allows for capital cost savings as well as recovery optimization for the MF unit (up to 98% recovery). Also, in applications where the feed water is relatively good (i.e. low feed water TSS or turbidity), chemical is dosed into the feed header to use the feed water as the makeup water for maintenance cleaning. Process schematic is represented in Fig. 3.

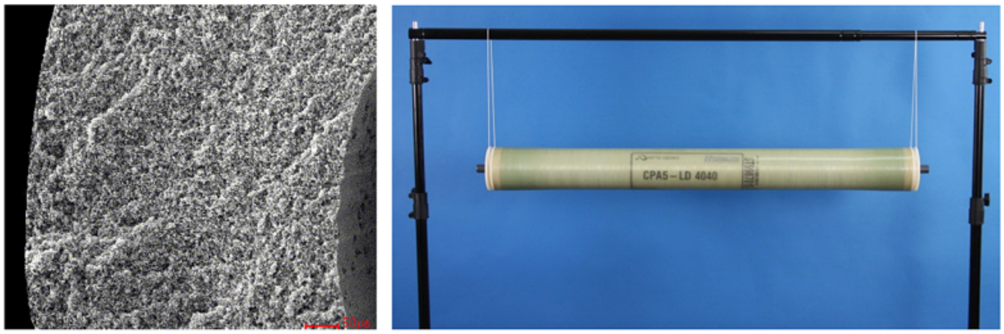
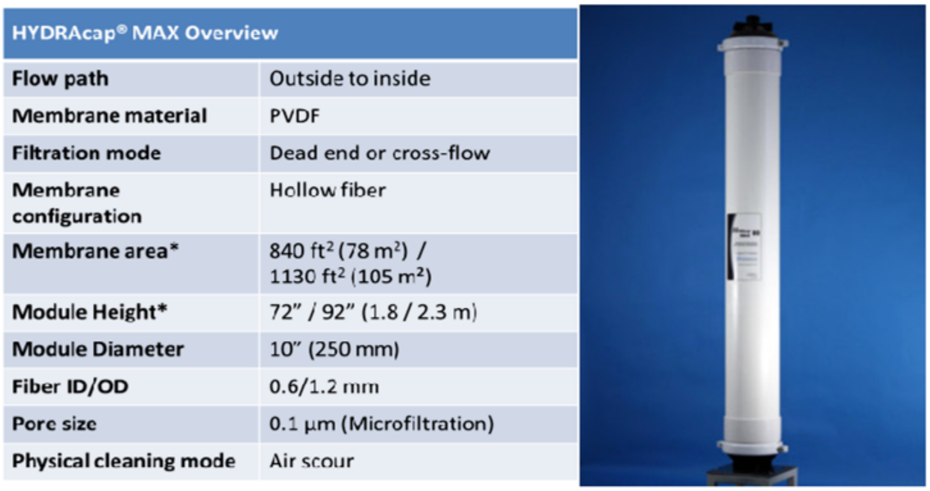


Fig. 1. Cross-section of PVDF fiber and example of the fibers physical resistance.



HYDRAcap® MAX Overview	
Flow path	Outside to inside
Membrane material	PVDF
Filtration mode	Dead end or cross-flow
Membrane configuration	Hollow fiber
Membrane area*	840 ft^2 (78 m^2) / 1130 ft^2 (105 m^2)
Module Height*	72″ / 92″ (1.8 / 2.3 m)
Module Diameter	10″ (250 mm)
Fiber ID/OD	0.6/1.2 mm
Pore size	0.1 µm (Microfiltration)
Physical cleaning mode	Air scour

Fig. 2. HYDRAcap® MAX physical characteristics.

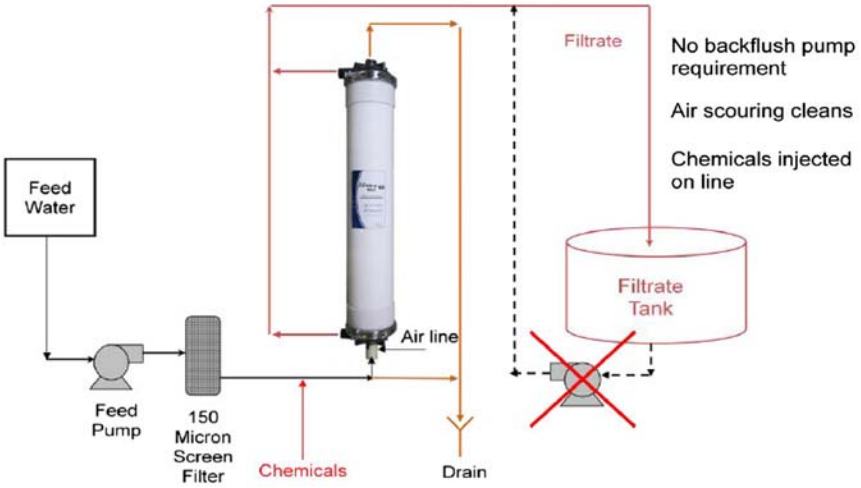


Fig. 3. Process schematic.

4. HYDRACAP® max operation

See Table 2.

4.1. Filtration mode

HYDRAcap® MAX systems can be operated in either dead end or concentrate bleed flow for more challenging waters. Filtration flux is assessed on a case-by-case basis depending on:

- Water source (well water, surface water, seawater, waste water)
- Water quality (turbidity, TSS, organic matter, metals, and alkalinity)
- Pretreatment
- Temperature

4.2. Air scour mode

The AS is the main mode used for cleaning PVDF fibers. Each HYDRAbloc® in the MF membrane plant sequentially enters into an AS mode after a preset amount of time passes (filtration time) or after the transmembrane pressure increases beyond a certain point. Rather than using an extensive volume of backwash water, air will be injected to the bottom of the module through a segregated air channel in the feed end adapter (air and water channels are separated). The air will then travel through an innovative air diffuser (patent pending), forming coarse air bubbles that will be distributed evenly to the external layer of the fibers. The air does not need to be pressurized more than the level of water in the MF skid. By scouring and gently agitating the fibers

Table 2
Operating modes

Operating mode	Typical duration	Typical frequency
Filtration–dead end or cross flow	20–60 min	
As–air scour clean	120–240 s	20–60 min
MC1–chlorine maintenance clean	20–30 min	1–2/day
MC2–caustic maintenance clean	20–30 min	1–2/day
MC3–acid maintenance clean	20–30 min	1–2/day
RC–recovery clean	2–3 h	1/1–3 months
MIT–membrane integrity test	10–15 min	As needed

with air bubbles, foulant is effectively removed from the membrane surface and then drained from the module. Depending on the feed water quality, the skid at this point can be returned to filtration (single AS mode) or another fill and drain can be implemented (dual AS mode). Therefore, the amount of waste water is roughly equal to one skid volume (single AS) or two skid volumes (dual AS) depending on rack design.

4.3. Maintenance clean mode

Maintenance clean (MC) is the primary means to chemically clean the membrane. It combines air scouring and chemical soaking. First, an AS is done in order to clean the external layer of the fibers. After the modules are drained, the skid can then be refilled with a chemical solution either through the feed line or filtrate line depending on the quality of the feed water. Table 3 describes the general chemical concentrations for each type of MC.

By soaking the membranes, the foulants deposited on the membrane surface and within the membrane pores will dissolve. Once the foulants have been broken down, another AS is conducted to further remove the solids. The next critical step is to pressurize the lumen of the fibers with air while draining, which helps to remove the chemicals inside of the fibers as well as allow for a slight expansion of the fibers optimizing foulant removal. The skid will then return to filtration after a chemical rinse, where the filtrate will be sent to drain to ensure no chemicals will be mixed with the product water.

4.4. Recovery clean mode

Recovery clean (RC) (or Clean in Place) is a supplement to the MC and is a more intensive chemical clean of the membrane. The process is similar to the MC, only with higher chemical concentrations and longer contact times. However, unlike the MC, the RC must use filtrate (or better) quality water as its makeup solution and should be heated to 40℃. The heated water (without chemicals) will first mix with the feed water already in the module to gradually heat the modules before introducing the heated chemical solution. This prevents thermally shocking the modules. The modules are next drained while air scouring and then refilled again this time with the heated chemical solution. Table 4 describes the general chemical concentrations for each type of RC.

After soaking, air scouring, and further soaking, the modules are drained and chemically rinsed in the same manner as the MC before resuming filtration.

Table 3
Maintenance clean chemical concentrations

Chemical solution	MC1 (chlorine)	MC2 (caustic)	MC3 (acid)
Sodium hypochlorite	200 ppm	–	–
Sodium hydroxide (50% NaOH)	–	1,200 ppm	–
Sulfuric acid (96% H_2SO_4)	–	–	1,470 ppm (0.15%)
Hydrochloric acid (33% HCl)	–	–	1,470 ppm (0.15%)
Citric Acid	–	–	4,000–8,000 ppm (0.4–0.8%)

Table 4
Recovery clean chemical concentrations

Chemical solution	RC1 (chlorine)	RC2 (caustic)	RC3 (acid)
Sodium hypochlorite	1,000 ppm	–	–
Sodium hydroxide (50% NaOH)	–	3,500 ppm	–
Sulfuric acid (96% H_2SO_4)	–	–	5,000 ppm (0.5%)
Hydrochloric acid (33% HCl)	–	–	5,000 ppm (0.5%)
Citric acid	–	–	10,000–20,000 ppm (1–2%)

4.5. Membrane integrity test mode

Membrane integrity tests are conducted to identify eventual fiber breakage. Air, approximately at 1 bar, is supplied to the filtrate side of the fiber to monitor the pressure decay over a period of 5 min. If there is a broken fiber(s), air will pass from the inside to the outside of the fiber(s) and leave the module through the concentrate port, causing the pressure in the filtrate header to drop. If the module fails the integrity test, the test may be repeated or the failed module may be removed from the HYDRAbloc® for fiber repair depending on the site requirements.

5. Case study

There are several pilot units in operation using HYDRAcap® MAX. This study will present a small amount of data from the Encina (California) pilot. The feed water for this pilot unit is seawater from a lagoon (see Fig. 4). The following lists the operating parameters of the pilot unit:

(1) Filtration of raw seawater after a 100 μ strainer
(2) 1 HYDRAcap® MAX 80 module (105 m^2)
(3) 80 lmh net flux
(4) Operating sequence

  (a) Filtration: 30 min
  (b) Air scour: 120 s, single AS and drain
  (c) Chlorine MC: 1/day with 200 ppm NaOCl
  (d) Acid MC: 1/week with 0.2% HCl

The Encina pilot operates at an average temperature of approximately 20°C with the temperature ranging from 13–30°C. Although the unit typically treats 1–2 NTU raw seawater, the unit has experienced more dif-

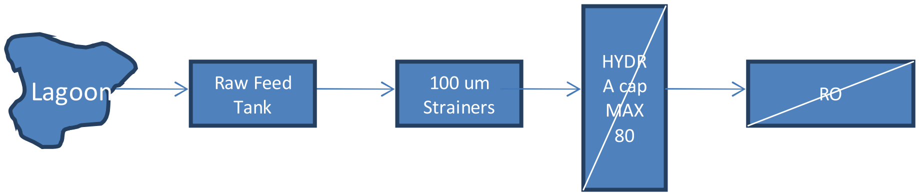


Fig. 4. Schematic of Encina pilot.

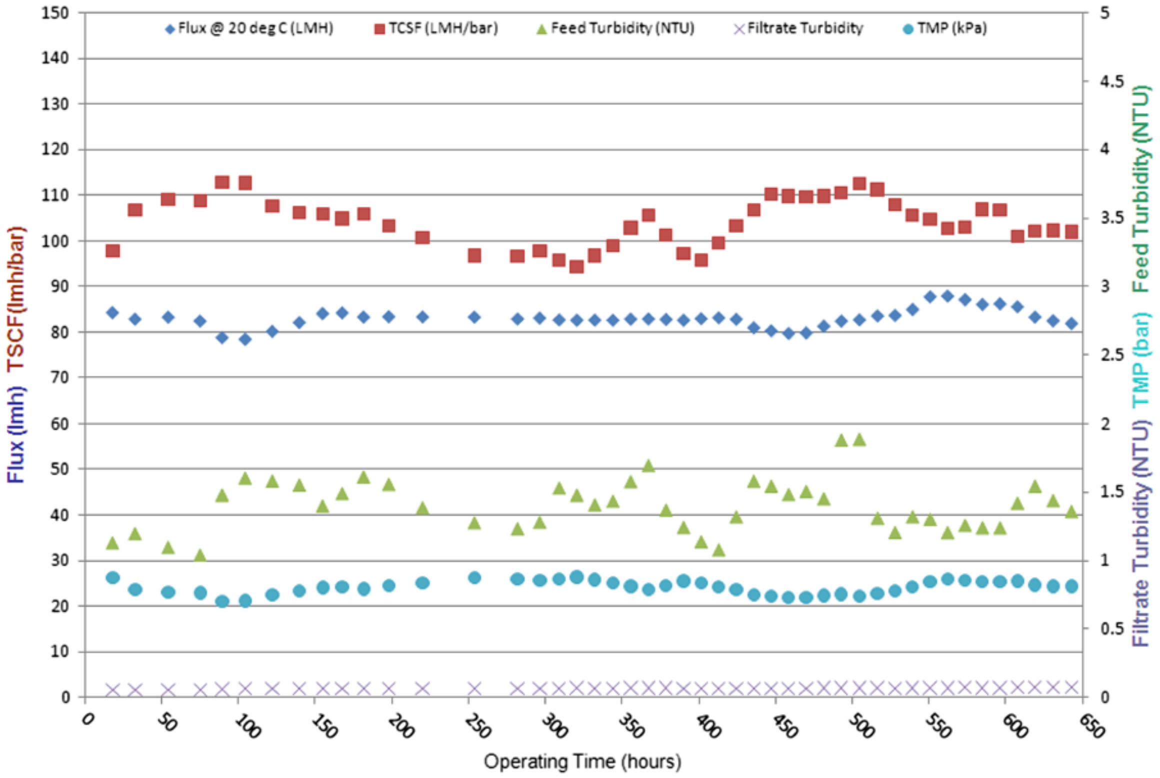


Fig. 5. Data from Encina pilot.

ficult feed waters caused by seasonal algal blooms, silt runoff deposits from rain, and low/high tides. The pilot unit has shown that the HYDRAcap® MAX can run stably as well as successfully treat this raw seawater at 80 LMH for an extended period of time without a recovery clean (see Fig. 5).

Along with other studies, hydranautics has further used this pilot to optimize the HYDRAcap® MAX operating process. For example, the efficacy of an AS, air pressurized assisted clean, and backwash was compared. In order to evenly evaluate the effectiveness of each cleaning procedure, a total AS time of 195 s was used in all three cases.

For the air pressurization test, air was supplied to the lumen of the fiber after every filtration cycle. The theory behind pressurizing and expanding the fibers is to help break loose foulant from the membrane surface as well as push out particulates plugging the fiber pores. When the module entered into the air pressurized assisted clean, the inside of the fiber was pressurized to 1 bar for 45 s while applying an AS. The pressure was then held for another 95 s while continuing to AS. The module was then drained while using an AS for 55 s and the pressure inside the fiber was vented during the refill.

For the backwash case, after the filtration cycle, an AS with backwash was conducted for one min. The concept behind this procedure is similar to the air pressurized assisted clean theory, but using water instead of air. In this procedure, since this is an out/in module, filtrate was sent back through the inside of the fiber and permeated outward. The backwash flux was set equal to that of the filtration flux (80 LMH). This means that the overall recovery would drop by approximately 4%, since the filtrate used for backwash was wasted. The module was then further air scoured for another 80 s before being drained while using an AS for 55 s.

The three tests were conducted sequentially over a period of 6 weeks in total (2 weeks each). Fig. 6 shows the results of each test superimposed on top of one another. Either 1 or 2 MC cycles were conducted per day depending on the quality of the water during the specific time of testing. Thus, to determine the efficacy of each physical cleaning method applied, the rates of permeability decline, as characterized by the orange lines, were examined. In conclusion, the study showed that an AS alone was just as effective as an air pressurized assisted clean or backwash.

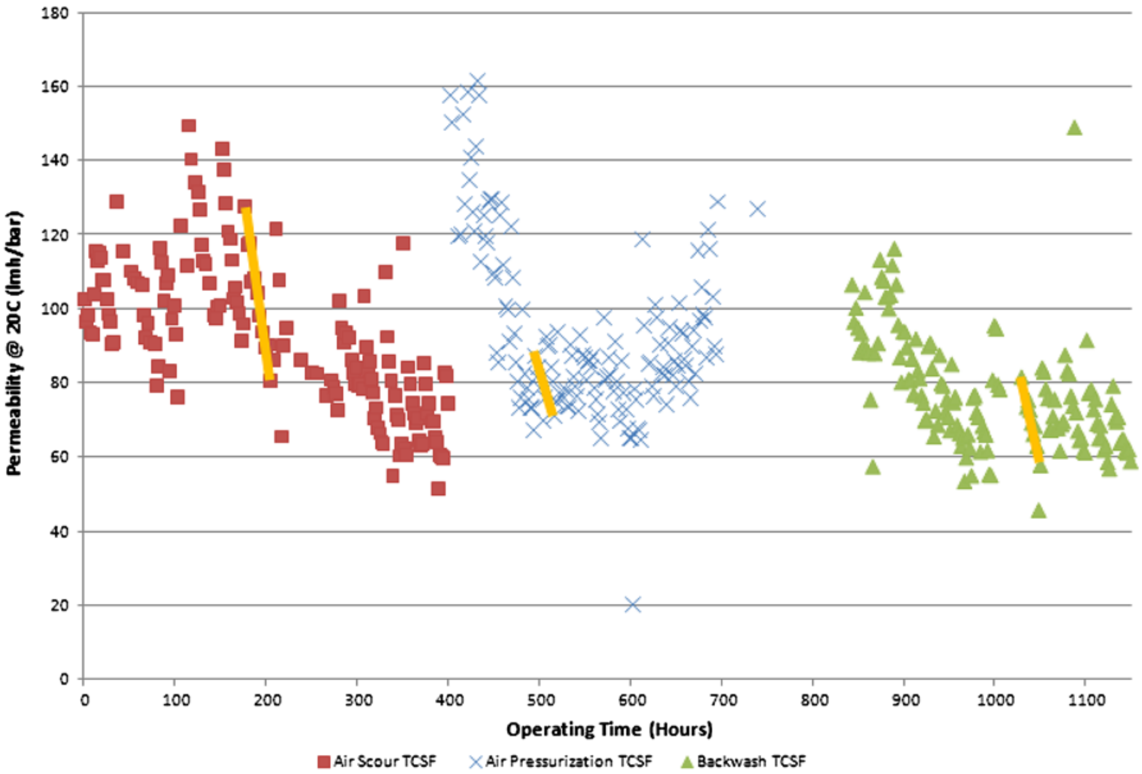


Fig. 6. Data from AS vs. air pressurization vs. backwash test.

Table 5
Feed water quality

Source	Surface water
Minimum temperature (℃)	12
Turbidity (NTU)	5
Total suspended solids (ppm)	10
Total dissolved solids (ppm)	200
COD (ppm)	10
BOD5 (ppm)	5
TOC (ppm)	5
pH	8.1
Iron (mg/L as Fe)	0.05
Manganese (mg/L as Mn)	0.02
Aluminum (mg/L as Al)	0.05
Alkalinity (mg/L as $CaCO_3$)	50
Total hardness (mg/L as $CaCO_3$)	50

6. Example system

This section will provide a detailed design to produce 14,500 m^3/day of raw surface water. Along with

Table 6
Summary of system information

Temperature corrected average gross flux (LMH)	75
Filtration time (mins)	30
Net filtrate flow (m^3/day)	14,500
Recovery (%)	97.9
Footprint size (m^2)	39.8
Total number of valves	26
Total number of duty feed pumps	2
Total number of blowers	1
Total daily consumption of 12% sodium hypochlorite (l/day)	12.44
Total daily consumption of 50% sodium hydroxide (l/day)	1.89
Total daily consumption of 96% sulfuric acid (l/day)	1.26
Average total feed pump energy consumption (kwh/m^3)	0.080
Average total blower energy (kwh/m^3)	0.0019

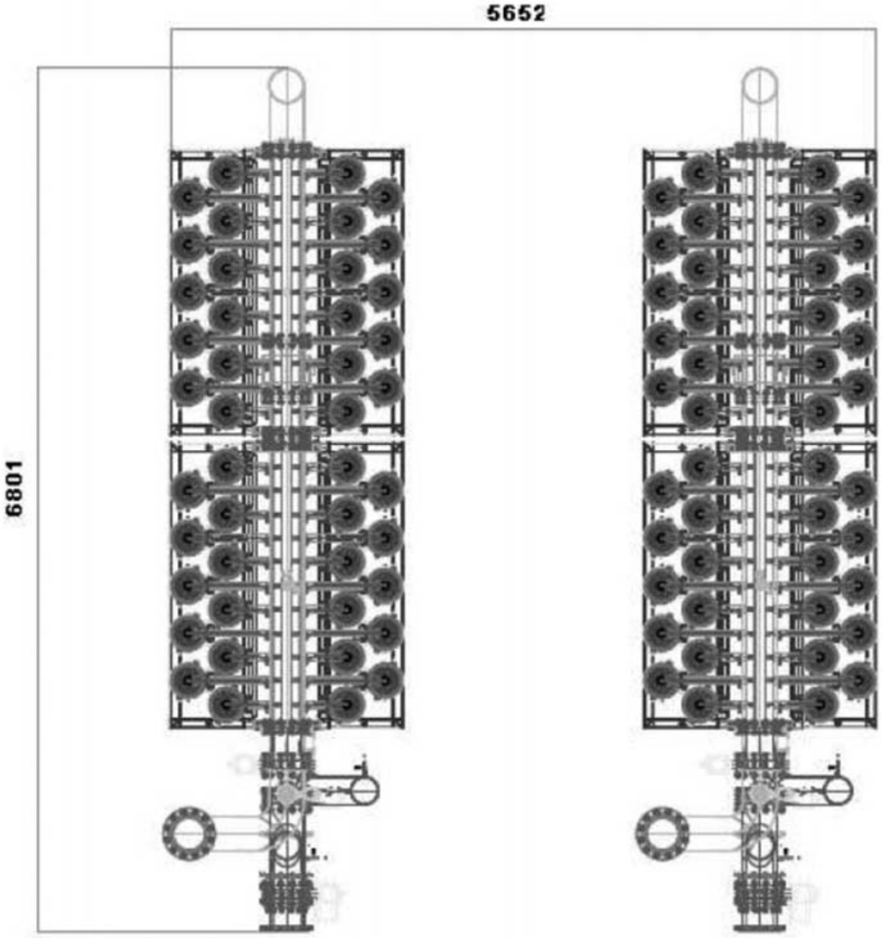


Fig. 7. Rack footprint drawing in millimeters.

Table 7
HYDRAcap® MAX as from August 2012

Country	Application	Expected start-up	Number of modules	Flow capacity (m^3/day)	Type of module	Feed water quality	Flux (Lmh)	Filtration timer (min)	Recovery expected (%)
Taiwan	Industrial waste water	Jun-12	6	350	HYDRAcapMAX60	1,000 NTU	35	25	85
Singapore	Recycled water	Sep-12	8	960	HYDRAcapMAX60	<2 NTU	73	40	98
Spain	Surface water	Sep-12	2	240	HYDRAcapMAX80	30 NTU	45	50	97
Australia	Surface water	Sep-12	1	144	HYDRAcapMAX80	5 NTU	40	30	95
Israel	Surface water	Sep-12	10	1,080	HYDRAcapMAX80	100 NTU	51	30	80
India	Surface water	Oct-12	8	640	HYDRAcapMAX80	100 NTU	50	30	94
China	Well water	Dec-12	76	9,600	HYDRAcapMAX60	5 NTU	79	30	98
China	Well water	Dec-12	76	9,600	HYDRAcapMAX60	5 NTU	79	30	98
Australia	Surface water	Dec-12	3	200	HYDRAcapMAX60	20 NTU	43	30	90
China	Industrial waste water	Dec-12	84	8,000	HYDRAcapMAX60	5 NTU	50	30	95

the main design parameters, the following items will also be evaluated: energy consumption, chemical consumption, and all necessary equipment/instrumentation required. The feed water quality is presented in Table 5. This system utilizes 2 racks of 44 modules (see Fig. 7) to produce 14,500 m^3/day of filtrate. The system runs at a constant flux of 75 LMH for 30 min in dead end mode. As the primary mode of cleaning, this system will employ a single AS with no backwash pump required. Maintenance cleans include 1 MC1 per day, 1 MC2 per week, and 1 MC3 per week. A summary of the system information for this case is provided in Table 6.

7. Reference list

See Table 7.

8. Conclusion

HYDRAcap® MAX offers an ideal solution to the system designer for pretreatment to RO and the reuse of waste waters by providing the following advantages:

- Compact design for optimal footprint.
- Design simplicity by removal of backwash pumps.
- Increased chemical and physical resistance through TIPS fiber technology.
- Even distribution of air within the module through an innovative air diffuser design.
- Operational flexibility to treat feed waters with up to 300 NTU.
- Dual potting layer to prevent fiber damage.
- Optimized recovery for water savings.