

**NEW COMPOSITE MEMBRANE AND ELEMENT
CONFIGURATION FOR RECLAMATION OF HEAVY FOULING
WATERS**

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1. ABSTRACT

Hydranautics is developing a new structure of composite membranes and new packaging configuration of spiral wound elements. The new membrane configuration, designated as SPIRAL BACKWASHABLE, consists of two novel concepts:

- Composite, flat-sheet RO membrane, which can withstand significant permeate flow rate in the reverse direction without membrane delamination.
- A new spiral wound element configuration, which enables the effective removal of fouling material from the membrane surface and the feed channels by applying reverse permeate flow (permeate backwash operation).

This new design has the potential to:

- Provide stable performance of composite RO membranes operating on secondary municipal effluent, which was treated only with media filtration.
- Simplify the configuration of RO systems treating municipal effluent by eliminating the need for extensive pretreatment.
- Reducing investment cost of RO systems treating heavy fouling water by reducing the scope of the required equipment.

The proposed work will include:

- Manufacturing a special structure of flat sheet composite membranes, which can withstand high rate of reverse permeate flow without structural damage.
- Developing new technology of sealing membrane envelopes to maintain membrane element integrity under the condition high permeate backpressure.
- Manufacturing a new configuration of spiral wound element, designed for the removal of foulants in the backwash step.
- Characterization of performance and operating parameters of a new device at standard test conditions.

- Conducting long term operation of new element configuration in field conditions with heavy fouling feed water.
- Defining operational parameters, backwashing sequence and the effectiveness of cleaning procedures.
- Evaluation of field results with respect to the effectiveness of the new design, process reliability and economics.

Field testing of the new membrane will be conducted in cooperation with the San Diego Metropolitan Waste Department.

The pilot RO unit will be operated at the San Pasqual Aquatic Treatment Facility, Escondido California.

2. BACKGROUND

2.1. INTRODUCTION

Application of reverse osmosis technology for municipal waste water reclamation traces back to the early stages of commercialization of the RO process. It was realized soon that application of membrane technology to treatment of municipal effluent represents a unique challenge due to a very high fouling potential of the treated streams. Therefore, development of effective pretreatment process and demonstration of performance stability was the main objective of the early works (1, 2, 3, 4). As early as in 1960's the City of San Diego conducted the first testing and demonstration program of application RO technology for augmentation of water supply by reclamation of waste water. This attempt was not successful due to severe membrane fouling (5). Since then, a number of field tests have been conducted at different sites, which enabled development of process parameters and system components of the future commercial plants (6, 7, 8, 9).

Application of reverse osmosis technology for waste water reclamation in Southern California runs parallel to commercial development of RO process. The first large

reverse osmosis plant, which processes waste water is a part of what is known as "Water Factory 21" in Orange County, California, commenced operation in the late-seventies. This RO system has 5 MGD of product capacity and reduces salinity of municipal waste water after tertiary treatment. Product water after blending is injected into local aquifers to prevent seawater intrusion (10, 11).

The next large RO system for water reclamation, the Arlington Desalter (12, 13), located in Riverside County, California, commenced operation in 1990. This system processes agricultural drainage water of about 1000 ppm TDS salinity, which contains high concentration of NO₃ (100 ppm) and SiO₂ (40 ppm). The plant produces 6 MGD of low salinity water by blending 4 MGD of RO permeate with 2 MGD of ground water. The blending ratio is determined by the limit of nitrate ion concentration in the blend water, which has to be below 40 ppm (12). Today, a large number of new membrane projects for municipal waste water reclamation are under design or extensive pilot testing. In the majority of them, the new, advanced membrane pretreatment methods are evaluated. The objective is to improve stability of performance of RO membranes and to improve process economics.

2.2. CONVENTIONAL PRETREATMENT

The municipal effluent after secondary treatment contains high concentrations of colloidal particles, suspended solids and dissolved organics. The municipal treatment process usually includes biological treatment (activated sludge clarification) which results in high level of biological activity in the effluent. Prior to RO, this effluent has to be treated to reduce the concentration of colloidal and solid particles and to arrest biological activity.

A typical configuration of conventional pretreatment is shown in Fig. 1, which outlines the tertiary pretreatment process applied currently at Water Factory 21. The current pretreatment process is a result of evolution, improvements and simplification of the original design (5). The pretreatment consists of flocculation, lime clarification, recarbonation with CO₂ and settling and slow gravity filtration.

The biological activity is controlled by applying chlorination. The lime clarification is a very effective process for improving feed water quality, but it is expensive, requires large area and produces sludge, which can be difficult to dispose. In some smaller systems the lime clarification and gravity filtration is replaced by in line flocculation followed by two stage pressure filtration and cartridge filtration. On the average, this simplified pretreatment produces effluent of lower quality than the lime clarification process, but the equipment is significantly smaller and simpler to operate.

The feed water after a conventional pretreatment has a high fouling potential. It is not uncommon that in water reclamation applications the RO membranes would experience 25% - 30% per year average flux decline, even with a frequent membrane cleaning.

2.3. ADVANCED PRETREATMENT

Use of membranes as a definite barrier in the RO pretreatment process has been proposed in the past (5). Ultrafiltration (UF) and microfiltration (MF) membranes have the ability to produce feed water of significantly better quality than the conventional pretreatment process based on lime clarification followed by media and cartridge filtration. However, the conventional, spiral wound configuration of ultrafiltration membrane elements was not suitable for treatment of highly fouling waste water. The spiral UF elements could not operate at high permeate flux rates without severe fouling of the membrane surfaces and plugging of the feed channels. High cross flow feed velocities, required to reduce concentration polarization, resulted in a high power consumption. Membrane cleaning, frequently required, was cumbersome and not very effective in restoring permeate flux.

The new microfiltration and ultrafiltration technology offered recently (14) is based on a fat capillary membrane configuration. The capillary bore is of 0.7 - 0.9 mm diameter. The outside diameter of the capillary is in the range of 1.3 - 1.9 mm. Membrane material consists of polypropylene, sulfonated polyether sulfone

or cellulose acetate polymer. In some capillary element design configuration the feed - permeate flow direction is outside - in (i.e. feed water flushes the outside of the capillary fiber, water permeates through the wall and is collected as a permeate inside the fiber). Other element configurations have an inside - out flow direction.

There are two common novel properties of the new commercial capillary equipment;

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

The off-line time due to pulse cleaning is very short, comparable to off line time of conventional filters due to filter backwashing. The frequent pulse cleaning of the capillary device results in stable permeate flux rates. The feed water pressure is in the range of 1 to 2 bar. Operation at low feed pressure and low rate of feed cross flow or in a direct filtration mode results in high recovery rates and very low power consumption, of about 0.4 kWhr/kgallon (0.1 kWhr/m³) of filtrate. The membrane type is either microfiltration (nominal pore size 0.2 micron) or ultrafiltration (molecular weight cut off 100,000 - 200,000 Dalton). The dimensions of capillary ultrafiltration modules are in the range of 40" - 52" (100 - 130 cm) long and 8" - 13" (20 - 32 cm) in diameter. In actual field operation, a single module can produce 8,000 - 40,000 gallons per day (30 - 150 m³/day) of filtrate. Compared to the conventional water treatment technology, the new process offers modular design, high output capacity from a small foot print, no need for continuous handling and dosing of chemicals, and limited labor requirements. The new capillary pretreatment is capable to produce RO feed water of very high quality, even from heavy polluted sources. This new pretreatment technology enables to maintain stable performance of composite

RO membranes in water reclamation applications. However, capillary technology is still quite expensive. On the average it may represent up to 50% of the total system cost. Use of capillary equipment as feed water pretreatment in RO systems is only justified for treatment of heavy fouling sources.

2.4. THE CONVENTIONAL SPIRAL WOUND CONFIGURATION

The concept of a spiral wound membrane element device was introduced shortly after the invention of the hollow fiber configuration (16). In a spiral wound configuration, two flat sheets of membrane are separated with a permeate collector channel material to form a leaf. This assembly is sealed on three sides with the fourth side left open for permeate to exit (Fig 2). A feed/brine spacer material sheet is added to the leaf assembly. A number of these assemblies or leaves are wound around a central plastic permeate tube. The permeate tube is perforated and collects the permeate from the multiple leaf assemblies. The typical industrial spiral wound membrane element is approximately 100 or 150 cm (40 or 60 inches) long and 10 or 20 cm (4 or 8) inches in diameter. The feed/brine flow through the element is a straight axial path from the feed end to the opposite brine end, running parallel to the membrane surface. The feed channel spacer induces turbulence and reduces concentration polarization. Spiral wound elements are most commonly manufactured with flat sheet membrane of either a cellulose diacetate and triacetate (CA) blend or a thin film composite. A thin film composite membrane consists of a thin active layer of one polymer cast on a thicker supporting layer of a different polymer. The composite membranes usually exhibit higher rejection at lower operating pressures than the cellulose acetate blends (17). The composite membrane materials may be polyamide, polysulfone, polyurea, or other polymers.

The spiral wound RO elements can not be used directly to treat heavy fouling feed water. For reclamation of this type of feed water an extensive pretreatment is require to remove particulate matter, which would otherwise result in fouling of RO membranes. Necessity of use of conventional or advanced pretreatment in

RO plants treating waste water, results in significant increase of system cost and operating expenses.

3. NEW MEMBRANE AND ELEMENT CONFIGURATION

3.1. THE BACKWASHABLE SPIRAL WOUND CONFIGURATION

The concept of backwashable spiral wound element configuration follows the similar approach as applied successfully in the new MF/UF capillary technology. In the above approach the elements operates at low cross-flow velocity. The foulant layer formed on the membrane surface is removed by applying frequent pulses of permeate flow in a reverse direction.

It is expected that such operation mode of spiral RO element will have similar effect as it is experienced during operation of the capillary MF/UF elements: i.e. lifting of colloidal foulants from the membrane surface and maintain stable permeate flux.

The major differences between the existing backwashable MF/UF capillary technology and the new spiral device are:

- a) Membrane material configuration: asymmetric capillary vs. composite flat sheet. The asymmetric capillary membrane is a uniform one material structure. The conventional composite membrane has a multilayer structure design to operate in one flow direction only.
- b) Membrane type: MF or UF vs. RO membranes. The RO membrane has much lower water permeability than MF or UF membrane and therefore backwash operation will have to be conducted at much higher pressure than in capillary MF /UF devices.

Therefore, there are two major problems, which have to be overcome to enable application of permeate backwash procedure to spiral wound elements made of composite membranes:

- a) During backwash operation (pressure driven permeate flow in reverse direction) there is a potential danger of delamination of the polyamide barrier skin layer from the polysulfone support.
- b) Backwash at excessive pressure may also result in braking of glue lines at the perimeter of membrane envelopes.

Delamination will result in membrane damage i.e. destroying the integrity of the salt rejecting top layer. In commercial composite membranes, delamination can occur if permeate pressure exceeds feed pressure by about 15 psi (1 bar). Driving force of 15 psi will probably result in reverse permeate flow of about 2 – 3 gallo/ft²-day (gfd), which is relatively low compared to the average permeate flow rate in normal direction of about 10 – 14 gfd. Short duration, pulses of reverse flow rate of 2 – 3 gfd probably will not be sufficient to dislodge colloidal particles, which have been attached to the membrane surface during operation in the normal direction of water flow (feed to permeate). In order to enable application of a higher permeate pressure (probably in the range of 60 –90 psi), which would result in a higher rate of reverse permeate flow, the configuration of flat sheet composite membrane would have to be modified to prevent membrane delamination.

Stability of glue lines in respect of permeate pressure applied in the inside-out direction is probably higher than the delamination stability of the membrane itself. However, most likely the current glue line design is not adequate to maintain long term element integrity for high frequency application of permeate pressure pulses. The glue line technology would have to be modified to increase its long term stability under high pressure burst conditions.

The new design of membrane element will most likely consist also of an open configuration brine spacer, which would allow more effective flushing out colloidal particles entrapped in feed channel during the normal operation. In addition, a new RO system configuration would have to be developed to assure

a uniform permeate flow, over the entire membrane surface, during backwash operation.

3.2. POTENTIAL BENEFITS OF NEW ELEMENT DESIGN FOR WATER RECLAMATION

Successful development of backwashable RO membrane elements could result in following technology improvement:

- Simplification of the water treatment system by combining the membrane pretreatment and RO desalting in a one step process.
- Reduction of investment cost due to reduction of required equipment.
- Reduction of operating cost due to potential reduction of power consumption.
- Reduction of plant site size requirements

These improvements will result in significantly better economics of water reclamation process, providing the same performance level as it is obtainable today by a combined process of capillary membrane pretreatment followed by RO desalting.

4. SCOPE OF WORK

The scope of work will include the following operations.

- Development of stable configuration of backwashable composite polyamide flat sheet RO membrane.
- Development of new membrane gluing technology, which would provide good sealing stability under conditions of high pressure inside the permeate channel.
- Development of new configuration of spiral wound element, designed for backwash operation
- Design and construction of pilot unit.
- Operation of pilot unit at the San Pasqual test site for the period of four to six months. The unit will operate on secondary municipal tertiary effluent treated with sand filtration.
- Evaluation of field results and optimization of operating parameters.
- Evaluation of membrane elements after field operation.
- Preparation of final report.

4.1. INITIAL TESTING

The new configuration of flat sheet membrane and backwashable elements will be tested initially at Hydranautics manufacturing facility. The objectives of the initial tests will be to establish performance at reference test conditions, test elements integrity and define acceptable range of operating parameters in respect of permeate pressure during backwash operation. Integrity of composite flat sheet membrane will be tested in flat cell apparatus. Measurement of salt rejection after each sequence of application of permeate pressure will be used as an indicator of membrane integrity. Also examination of membrane surface will be conducted using optical and electron microscopy. Integrity of membrane

elements will be determined by measuring salt rejection and conducting vacuum and bubble test.

4.2. FIELD TEST OPERATION

The objective of field operation is to determine long term stability of backwashable membrane elements in respect of integrity and performance and optimization of the operating parameters.

During operation of the pilot unit the following tests and data collection will be conducted:

- Daily recording of the parameters of the quality of the feed water. The measured parameters will include feed temperature, feed conductivity, feed turbidity, feed silt density index (SDI), feed pH.
- Daily recording of the operating parameters of the pilot unit and performance of membrane elements. The recorded data will include flows, pressure and conductivities.
- Periodic monitoring of particle concentration in permeate.
- Periodic conductance of virus challenge tests.
- Periodic conductance of membrane element integrity test.
- Periodic conductance of complete analysis of chemical composition of feed, permeate, and concentrate.
- Periodic conductance of chemical cleaning of membrane elements.

After completion of the field operation the elements will be returned to Hydranautics. At Hydranautics facility all elements will be individually tested again to establish performance at the reference test conditions and to determine elements integrity after field operation. Afterwards selected elements will be autopsied. Samples of membrane will be examined using Scanning Electron Microscope (ESM) and composition of the surface layer will be examined using X-ray Electron Dispersion (EDX) and Infrared Spectroscopy (FTIR).

5. SCHEDULE

The following testing schedule is planned for the project:

Development of backwashable flat sheet composite membrane.	0 – 6 month
Development of backwashable spiral wound membrane element configuration.	3 – 6 month
Design and construction of pilot unit.	4 – 6 month
Operation of pilot unit.	7 – 10 month
Conducting of in house testing of return elements.	at 11 th month
Evaluation of results and preparation of final report.	at 12 th month

The above time schedule represents elapsed time from the project startup.

6. PROJECT MANAGEMENT

The project will be conducted jointly by

1. Hydranautics, represented by Dr. Mark Wilf

Hydranautics will formulate the field test program, evaluate results and prepare reports.

Hydranautics will develop backwashable composite membrane and backwashable membrane element configuration.

Hydranautics will provide the pilot unit and membrane elements for testing.

Hydranautics will conduct evaluation of membrane elements and conduct membrane surface analysis.

Hydranautics will evaluate operational data of pilot unit operation.

2. San Diego Metropolitan Waste Department, represented by Mr. Paul

Gagliardo

SDMWD will participate in formulation of the field test program.

SDMWD will make available the test facility (San Pasqual site) for conducting pilot test.

SDMWD will provide manpower for supervision of pilot test operation, data recording and maintenance.

SDMWD will participate in evaluation of results and preparation of reports.

7. PERSONNEL QUALIFICATIONS

Hydranautics

Mark Wilf, Ph. D., Principal Investigator.

Dr. Mark Wilf works at Hydranautics in the position of Director, Technical Support. He has been working in the field of reverse osmosis and water treatment for over 20 years. He is an author of over 30 technical publications in this field.

Mr. John Tomaschke

Mr. Tomaschke works at Hydranautics in the position of Director, Membrane Development Department. He has been working in the field of membrane development for over 20 years. He is an author numerous publications and patents in this field.

Mr. Estvan Ary

Mr. Ary works at Hydranautics in the position of Manager, Analytical Group. He has been working in the field of membrane development and membrane surface characterization for over 20 years. He is an author of numerous technical publications in this field

Mr. Steve Alt.

Mr. Steve Alt works at Hydranautics in the position of Application Engineer. He is experienced in operation of pilot units and evaluation of field data.

San Diego Metropolitan Waste Department

Mr. Paul Gigliardo - AWT Program Management and technical Director

Mr. Daniel Smith - Aqua 2000 Operation

8. FACILITY AND EQUIPMENT DESCRIPTION

The field operation of pilot unit will be conducted at San Pasqual Wastewater Reclamation Plant. At the San Pasqual facility the following equipment is available.

8.1. SAN PASQUAL SITE

Site description included in Appendix A.

8.2. HYDRANAUTICS

At Hydranautics manufacturing facility the following equipment is available and will be utilized for the above project:

- Bubble test equipment.
- Vacuum test equipment.
- Dye test rig.
- Test unit for testing performance of individual elements.
- Equipment for conducting autopsy of returned elements.
- Scanning Electron Microscope.
- EDX equipment.
- FTIR equipment

9. BUDGET JUSTIFICATION

The total budget requirement for the above project is estimated to be about \$280,000. The budget is composed of the following categories:

Category	Cost	WERF cost
Salaries	\$160,811	\$80,394
Equipment	\$72,000	\$36,000
Supplies	\$12,000	\$6,000
Analysis and elements evaluation	\$26,000	\$13,000
Domestic travel	\$2,000	\$1,000
Data evaluation and reports	\$8,000	\$4,000
Total	\$280,811	\$140,394

Significant part of the work in this project will include development of entirely new configuration of backwashable composite membrane and membrane element. The membrane development work will include formulation of number of potential membrane structures, which will be followed by preparation of small membrane samples. The membrane samples will be tested for suitability in the lab scale. The promising membrane configuration will be scaled up on the commercial membrane casting machine. In parallel a new concept of spiral wound membrane element will be developed. The above tasks will involve work of professionals experienced with development of flat sheet membranes, element design, membrane and element manufacturing and membrane examination. Significant part of the work will have to be completed before beginning of the field test. This division of workload is reflected in budget distribution: i.e. allocating larger amount of budget for the development and analytical work. Manufacturing of new element configuration will require specialty parts and unique pilot test equipment will have to be built. Travel will be limited to driving

the test site to supervise test operation and possibly one domestic travel to visit manufacturer of specialty equipment. Data evaluation and report category will include computerized modeling of spiral elements configuration, data processing from field operation and preparation of quarterly and final reports. From the total budget of \$280,811 Hydranautics request from WERF funding of \$140,394 (50%). The rest of the budget, will be provided by Hydranautics (\$95,156) and City of San Diego (\$25,261) as a salary payment and in-kind contribution of equipment, operation and supplies.

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