

RECYCLING AND REUSE OF DESALINATED SEAWATER

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ABSTRACT

Desalination of seawater provides high quality water that is used for both municipal and industrial purposes. In most cases the desalinated water is used once and then after being treated as wastewater is discharged back to the sea. In contrast, fresh water in large inland river systems is recycled and reused. This occurs when downstream users pump water that contains discharge from a wastewater treatment plant. Modern membrane technology allows desalinated water to be used more than once by purifying wastewater treatment discharge. It is not considered politically or socially acceptable to recycle this water for potable use, but the water quality is more than adequate for industrial use.

This paper presents the technology that is capable of treating wastewater, discusses how this technology is suitable for the challenges presented by wastewater treatment, presents examples of what can be expected as water quality, and presents the results of a plant handling wastewater.

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1. Introduction

Water is a strategic resource in the world. Historically, inland water resources are used, recycled, treated, and discharged back into a body of water to be used by another downstream user. Inland water recycling has even evolved to zero liquid discharge (ZLD) plants, where recycling of water is taken to the maximum extent possible. In this type plant, the only water used by the plant is make-up water for evaporation, production, and venting losses.

Recycling and reuse of desalinated seawater has not been utilized to a great extent. Seawater is normally desalinated, either by membrane or thermal means, utilized for either municipal or industrial reasons, treated, and returned back to the sea. This paper discusses the challenges to reusing municipal industrial/municipal wastes and describes proven technology that effectively converts wastewater into a high quality water that is suitable for use directly in the majority of industrial processes. Economics will always drive when and where new technology is applied. To this extent, capital, operating, and maintenance costs are qualitatively discussed which demonstrate the feasibility of such water reuse technology.

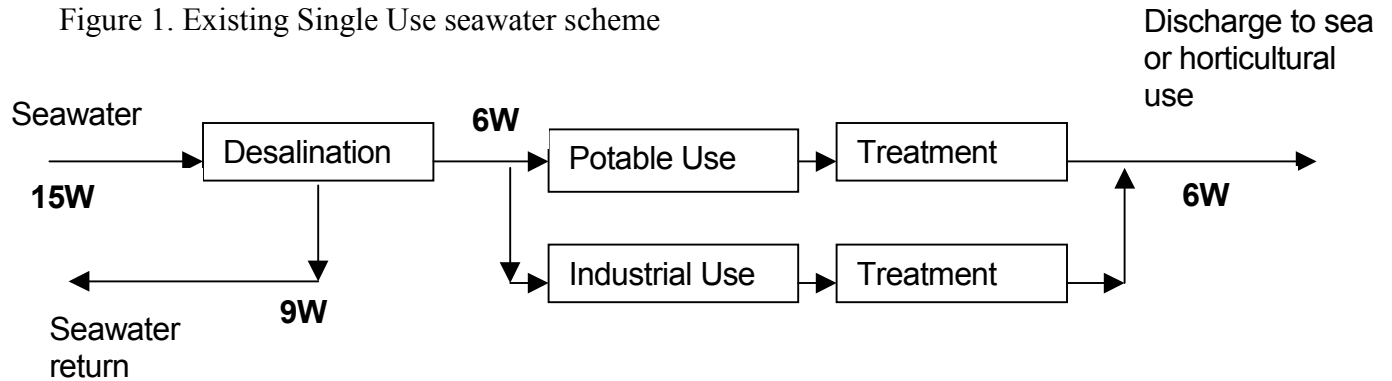
Patented advanced membrane technology has been applied by Aquatech International Inc. to recover wastewater from difficult to treat sources. A brief discussion of the process technology, equipment utilized, process waters handled, and examples of operating plants are presented.

2. Water Reuse Technology

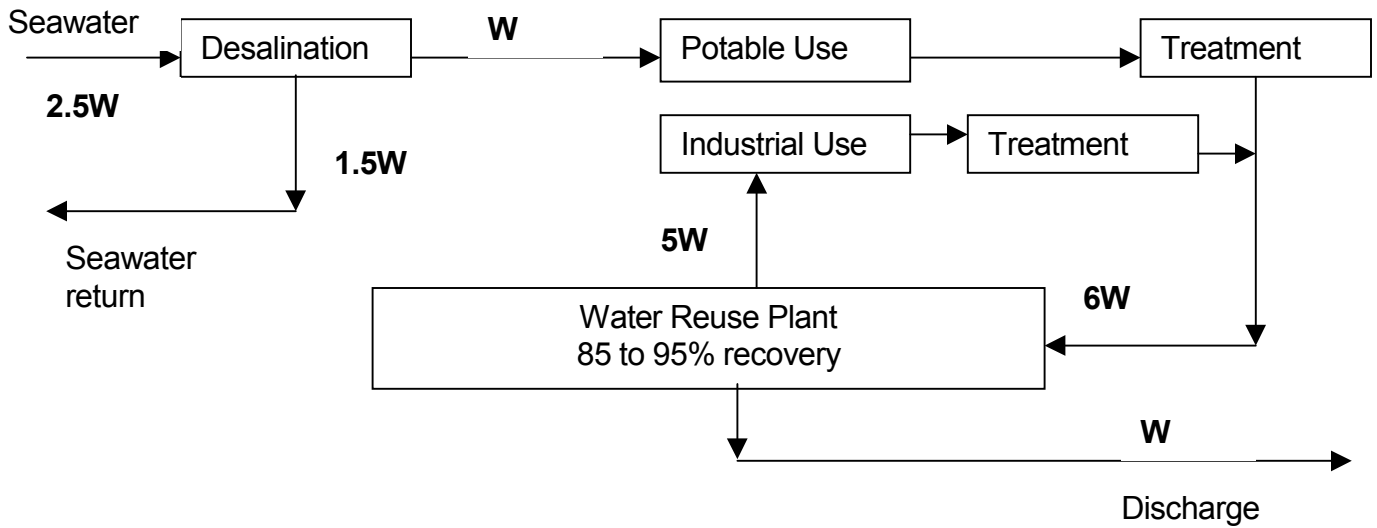
Technical Overview

In general, the block flow diagram in Figure 1 summarizes the Single Use flow scheme typically utilized when seawater is the feed water source. Note that 'W' marks the water required by downstream users, either Industrial or Municipal.

Figure 1. Existing Single Use seawater scheme



The block flow diagram in Figure 2 below summarizes the Water Reuse scheme discussed in this paper.



Introducing a Water Reuse Plant operating at high recovery, as shown in figure 2, the total water demand is maintained while the requirements of the Desalination plant are significantly reduced.

Feasibility of this Water Reuse scheme depends on two major factors;

1. Technology is available to process wastewater high in organic content, COD, BOD, particulate matter, and other severely fouling contaminants that is traditionally discharged from the Treatment plants.
2. Economics of the Water Reuse Plant are favorable compared to adding the same capacity in a Desalination Plant. Capital cost, operating cost, and maintenance considerations must be evaluated versus the typical Single Use scheme shown in Figure 1.

It has been demonstrated by Aquatech International Inc. that advanced membrane technology can effectively recover historically difficult waters such as Tertiary Treated Effluent and Refinery Waste at recoveries in the range of 85 to 95%, depending on the constituents in the wastewater. It can also be shown that the economy of using this technology is very favorable.

Recovery of Wastewater Treatment Plant Effluent

Two typical Wastewater Treatment Plant (WWTP) effluents are discussed in this paper; Municipal Tertiary Treated Sewage Effluent and Refinery Wastewater. Typical contaminants and contaminant levels for both waste types are shown below:

Municipal Tertiary Treated Effluent

Contaminant	Typical Levels in Effluent Discharge (all as mg/l unless noted)
BOD*	<20
COD*	10 to 60
Suspended Solids*	1 to 6
Colloidal Matter	varies
TDS	500 to 1500
Sparingly soluble salts	<200 hardness

* COD, BOD, and Suspended solids are typically the regulated parameters for discharge

Refinery Wastewater

Contaminant	Typical Levels in Effluent Discharge (all as mg/l unless noted)
BOD	10-100
COD	10-600
Suspended Solids	3-10
Colloidal Matter	varies
TDS	500-2000
Sparingly soluble salts	<200 hardness
Oil and grease	3 to 8

Note that Refinery Waste has additional contaminants beyond Tertiary Treated Effluent such as hydrocarbons, phenols, and other organics. Oil and grease is very detrimental to RO membranes.

Challenges for Recovery of WWTP Effluent

The fouling and scaling potential for the contaminants found in Tertiary Treated Effluent and Refinery Wastewater is rather high. Traditional membrane technology can be applied, however significant pretreatment to avoid fouling of the membrane is typically required. In refinery waste, organics, oil and grease levels are normally well above the limits published by membrane suppliers. The following table describes the typical contaminants and problems that the contaminants can cause:

Contaminant	Challenges to traditional RO technology
TOC/COD/Organic	Organic substances absorb on the membrane and can cause a severe decline in membrane flux which is irreversible in some cases.
Oil and Grease	Oil and grease absorb on the membrane surface even at very low levels of 0.1 mg/l. The effect is a decline in membrane flux.
BOD/Biological Matter	Membranes offer an ideal environment for microorganisms to live and grow. Biological fouling of membranes seriously affects performance and is difficult to remove.
Colloidal/Particulate Matter	Silts, Dead Biomass, clay, pretreatment coagulants will foul membranes and impair performance and salt rejection of membranes.

Reuse Technology for WWTP Effluent Recovery

There are two membrane technologies which have been applied to recovery of WWTP effluent. These technologies are discussed and compared below:

Traditional RO technology

The challenges to recovering WWTP effluent using traditional RO technology has been previously discussed. Extensive pretreatment of WWTP effluent is normally required to employ traditional RO technology. Further, the performance of traditional RO technology is very susceptible to variations in water composition. The following table summarizes the pretreatment steps required to avoid scaling/fouling of the RO membranes:

Contaminant	Pretreatment Required
TOC/COD/Organic	Coagulation/Flocculation/Clarification
Oil and Grease	Oil separation/flocculation/Filtration and absorption on Activated Carbon.
BOD/Biological Matter	Chlorine Disinfection, sanitation using proprietary biocides, UV sterilization, micro or ultra filtration, or activated carbon filtration.
Colloidal/Particulate Matter/SDI reduction	Coagulation with polymer followed by Media Filtration

Typical water recovery of a RO plant is in the range of 60% to 85% using WWTP effluent as feed water. Due to the pretreatment required, sampling and testing manpower requirements can be significant. Complex cleaning and backwash systems are required.

HERO™ system technology

This process can handle any number of difficult wastewater feeds including Tertiary Treated Effluent, Secondary Treated Effluent, and Refinery Waste. The detailed design of the HERO™ process is not within the scope of this paper, however, the following summarizes the important process steps included in the HERO™ system:

1. Elimination of wastewater feed hardness
2. Removal of alkalinity
3. Operation of the system at high pH

The following table highlights how normal WWTP effluent contaminants are handled in a HERO™ system:

Contaminant	HERO™ Advantage
TOC/COD/Organic	Adsorption and fouling of organic matter on the membrane is eliminated by high pH operation.
Oil and Grease	In alkaline pH conditions, the oil and grease are converted to soluble soaps eliminating chances of fouling on the membrane.
Silica	Silica solubility increases significantly at elevated pH.
BOD/Biological Matter	Biological activity at high pH is non-existent. Bio-fouling is eliminated.
Colloidal/Particulate Matter/SDI reduction	The force of attraction, or Zeta potential, is drastically reduced between the particle and the membrane in high pH operation. The possibility of particle adhesion to the membrane is greatly reduced. No SDI control is required.

With the HERO™ system, recovery is only limited by osmotic pressure. Note that pretreatment for common WWTP contaminants is essentially eliminated using a HERO™ system. The system is very easy to operate and the manpower requirements are low.

Economic Advantages of the HERO™ include:

- High recovery and high flux due to the non-scaling conditions in the system result in high water production per unit of membrane surface
- No SDI (Silt Density Index) limitation which eliminates the need for expensive pre-treatment equipment such as Micro-filtration, or Ultra filtration
- Very Low Cleaning Frequency. The HERO™ system essentially operates in cleaning mode due to the pH environment. Most types of fouling never occur, actual cleaning downtime is greatly reduced.
- No proprietary chemicals. HERO™ system operates on conventional chemicals. It does not require any expensive anti-scalants or cleaning chemicals
- Very high rejection of all contaminants, in particular organics and silica, resulting in vastly simplified downstream treatment processes

Comparison of Traditional RO technology to HERO™ system technology

Parameter	Traditional RO	HERO™ system
Possible recovery	60 to 85%	85% to 95% or greater
Power consumption	Low	Low
Pretreatment requirement	High	Low
Chemical type	Proprietary and basic chemicals	Basic chemicals only
Manpower requirement	High	Very low
Sensitivity to feed variations	High	Low
System complexity	Complex	Very simple
Power requirement	Low	Low
Membrane type	Brackish water, fouling resistant	Standard Brackish water
Allowable membrane flux	Low	High
Cleaning frequency	High	Low

While the traditional RO has been applied to WWTP effluent recovery, the HERO™ system clearly offers many advantages over the traditional system under many circumstances. The use of traditional RO has proved fragile, prone to plant upsets and difficult to operate.

Examples of successful installations and pilot studies of WWTP effluent recovery are presented in the next section.

WWTP Reuse Plant Installations

Aquatech International Inc. has supplied numerous Reuse Plants which recover WWTP effluent. Two such operating plants and one pilot plant study are briefly described below.

Tertiary Treated Sewage Effluent Recovery using Traditional RO technology

Aquatech International Inc. (AIC) has supplied a 30,000 m³/day plant in Singapore which operates using Tertiary Treated Sewage Effluent as the feed source. Detailed design of the plant is beyond the scope of this paper. However, the following summarizes important design concepts of the plant:

- Numerous technologies were considered for the duty, however RO with traditional dual media filtration (DMF) was selected due to the associated low cost of filter media and the very high recovery (99%) that the DMF can achieve.
- The AIC plant is designed to operate at 80 to 85% total recovery.
- High recovery is required since the cost of the tertiary treated effluent feed source in Singapore is significant. This fact emphasizes that water in any form (raw, treated waste, etc.) is more and more becoming a very strategic and valued resource.
- The product water from the AIC plant is used to supply an industrial center with High Grade Industrial Water (HGIW).
- Salt rejection of the wastewater is good.
- The plant is equipped with numerous design features specifically included for operation on Tertiary Treated water at high recovery. These include biologically resistant RO membranes, automated water management for back-washing/flushing/and draining, and variable frequency drives for energy conservation.

Secondary Treated Sewage Effluent Recovery using HEROTM technology

Aquatech International Inc. has supplied a 2400 m³/day HEROTM system to the Bajio Power Plant located in Mexico. The plant design is as follows:

- The plant is designed for 85% recovery but can be operated >90% recovery with inlet TDS of 1000 mg/l.
- Wastewater feed is Secondary Treated Sewage with 30 ppm BOD and 200 ppm COD, and 15 ppm oil and grease. This wastewater is significantly more difficult to handle than Tertiary Treated Sewage and contains slaughterhouse wastes.
- The wastewater contains a significant amount of silica.
- Permeate from the HEROTM system is demineralized water for power generation.

The water treated would have proved extremely problematical for traditional RO.

Secondary Treated Refinery Waste Recovery using HEROTM technology

A pilot study was completed using HEROTM technology to recover Refinery waste at the Indian Oil Corporation, in Panipat India. A brief description of the results follows:

- The pilot was operated at 90% recovery for more than 35 days
- 98% salt rejection was observed in the testing
- No increase in axial pressure drop was observed in the testing, indicating no fouling occurred
- No chemical cleaning was done on the membranes
- No anti-scalants were used
- The system was never checked for Silt Density Index; allowing the system to be exposed to colloidal/particulate matter
- Using Reject recycle, higher than normal levels of BOD, COD, particulate, and oil/grease were achieved to subject the system to very rigorous conditions
- No performance decrease was observed over the course of the test

3.0 Economics of Water Reuse

The previously discussed block diagrams, Figure 1 and Figure 2, will be used to demonstrate the technical and economic advantages of implementing a Water Reuse Scheme.

Figure 1. Single Use Scheme

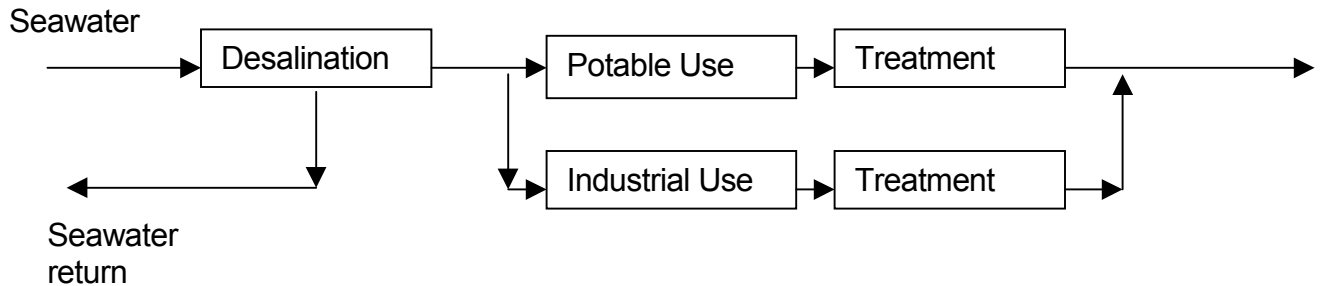
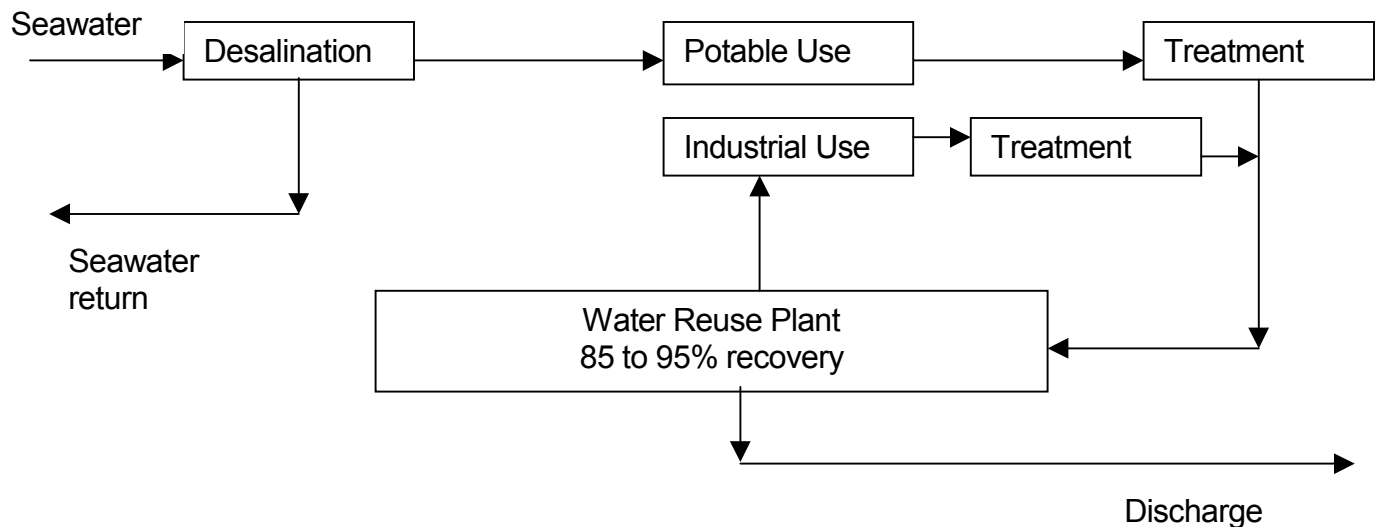


Figure 2. Water Re-use Scheme



It has previously been shown that by installing a Water Reuse Plant, shown in Figure 2, water demand can be maintained with a significantly smaller Desalination Plant. However, in order for the Reuse technology to be considered, it must have economic advantages over Desalination technology.

From a conceptual level, several advantages of the Reuse Scheme are apparent. Compared to Seawater Desalination, the feed water TDS is low and the recovery is high in the Reuse scheme. Membrane pressure and reject flow is much lower in the Reuse Scheme, therefore pumping power is much lower than SWRO membrane technology. A table comparing Water Reuse membrane technology vs. SWRO membrane technology is shown below.

Comparison of SWRO Desalination and Water Reuse membrane technology

Parameter	SWRO Single Use Scheme	Water Reuse Scheme
Feed water TDS, mg/l	35,000	1,000
Water recovery	40%	85 to 95%
Osmotic Pressure Required	High (68 bar)	Low (10 bar)
Permeate Quality (single pass basis)	350 mg/l at 68 bar	10 mg/l at 10 bar
Pumping power per unit water	High	Low
Seawater intake structure	Required	Not required
Membrane Type	Seawater	Brackish
Membrane Cost and Life	High Cost, 3 year life	Lower cost, 5 year life

The above table demonstrates that economics of a Reuse Plant appear favorable, at least at a qualitative level.

The comparison is a simple qualitative comparison only, no attempt to quantify the comparison is made since the factors that drive economic decisions change on a case by case basis. In actual practice, a detailed economic analysis must be done, on a case by case basis, to determine whether a Reuse Scheme is feasible.

Although the focus of this paper was on water production, environmental considerations (reducing WWTP discharge) might also drive the economics of a Reuse scheme. In some cases, Reuse plant economics might be driven solely by environmental regulations to decrease WWTP discharge.

4.0 Summary and Outlook

Reuse and recycle of inland water supplies has been practiced for many years. Recycle and reuse of Desalinated water has not been historically practiced. The objective of this paper was to demonstrate that 1.) Advanced membrane technology to recover highly contaminated WWTP effluent exists and has been proven and 2) Water Reuse technology economics are favorable compared to Desalination technology. Both objectives were confirmed in this paper.

Traditional membrane technology designed with special consideration for highly fouling/scaling WWTP effluent has been applied. In many cases, the patented HEROTM system offers economic and process advantages in recovery of WWTP effluent for reuse.

When compared to SWRO Desalination, the economic advantages of a Water Reuse Scheme are justified on a per unit water basis. The Water Reuse Scheme has capital, operating, and maintenance advantages over a SWRO Desalination plant on a qualitative basis. In actual practice, a case by case economic analysis is required to determine whether a Reuse scheme is justified.

Technology such as Water Reuse is required to satisfy the continually growing demand for clean water and needs to be seriously considered when evaluating required water resources. Water Reuse using membrane technology has evolved over time to a point where very difficult to treat wastewater can now be recovered. Due to the availability of the technology and the available economics, Recycling and Reuse of Desalinated Water should be considered and utilized.