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Simultaneous power recovery of gauge and osmotic pressure from brine of SWRO desalination plants

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ABSTRACT

The process of recovering gauge pressure from SWRO desalination plants is well known, and based on implementation work exchangers like DWEER or ERI. The possibility to recover osmotic pressure as mechanical work was developed by Prof. Sidney Loeb 30–35 years ago and patented by the Ben-Gurion University of the Negev. Till now the osmotic pressure present in SWRO brine stream was practically not recovered. The paper presents a way that allows simultaneous power recovery of gauge and osmotic pressure. Simultaneous power recovery of both power sources gives a higher power yield then the two processes applied separately. Recovery of osmotic pressure is made by high fluxes and requires an effective membrane cleaning method. The paper presents a direct osmosis high salinity (DO-HS) membrane cleaning technology. The DO-HS technology provides a new approach to keeping membranes continually clean by frequent and short membrane backwash. RO membranes can be backwashed on-line ones a day without stopping a high pressure pump or decreasing the RO separation pressure. A few second injection of NaCl solution redirects the process from RO to DO and within 1 min the membranes are cleaned, and the process comes back to RO production.

Keywords: Power recovery; Brine; SWRO; Direct osmosis high salinity technology

1. Introduction

The possibility to recover osmotic pressure as mechanical working power was foreseen by Prof. Sidney Loeb 35 years ago and patented by thr Ben-Gurion University of the Negev under US Patent No. 4,193,267. Until now, the osmotic pressure present in SWRO brine stream has not been practically recovered. This paper addresses osmotic power recovery by the penetration of low osmotic and gauge pressure wastewater into high osmotic and gauge pressure seawater RO brine. Power is recovered simultaneously from gauge and osmotic pressure with commonly used work exchangers.

Statkraft, a leading renewable energy player in Europe, based in Norway, implemented an osmotic power generation system based on the penetration of river to ocean water through semi-permeable membranes.

River water has a low osmotic pressure, below 0.3 bar, as well as a low gauge pressure. Seawater is pumped up to a gauge pressure of about 30 bar, which is equal to its natural osmotic pressure. The high osmotic pressure of the seawater allows the river water to penetrate the RO membranes, producing an additional volume of high gauge pressure and reducing its osmotic pressure. Energy from this additional volume can be recovered with a hydraulic turbine and converted to electricity using an electric generator.

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Dedicated to Prof. Sidney Loeb (1916–2008). December 14, 2009, Sede-Boker, Israel

The following are the disadvantages of using the Statkraft technology:

- *Water treatment* — Both the river and seawater must be intensively cleaned to remove all suspended solids prior to contact with the RO membranes. This requires significant capital, operation and maintenance expenses, as well as coagulant, flocculent and power expenses associated with this treatment.
- *Pumping energy* — Seawater has to be pumped to a pressure of about 30 bar and kept pressurized by energy recovery systems such as DWEER or ERI. This incurs capital, operation and maintenance expenses related to intake structures and pumping housings on both the ocean and river sides, which must be considered.
- *Energy transfer efficiency* — Energy losses associated with intake and transportation of two streams, as well as energy losses in the turbine and electrical generators, must be considered.

Osmotic power generation that is not associated with an SWRO plant does not appear to be cost efficient.

The interconnection of seawater desalination and simultaneous recovery of its brine osmotic power with its gauge pressure provides several benefits:

- SWRO brine solution is twice as concentrated and contains twice as much energy as seawater.
- SWRO brine already includes, in the cost of the desalinated water, the costs of the intake and pretreatment structures, as well as that of the related O&M and reagents required for filtration. The stage of osmotic power recovery receives SWRO brine free of charge. We will see later that brine salinity will be reduced to the level of natural seawater, which in itself is a significant ecological benefit.
- The process of recovering only gauge pressure from RO desalination plants is well known. The gauge pressure recovery process is based on work exchangers such as DWEER or ERI. Until now, the osmotic pressure has not been recovered from the brine stream.

The approach presented here allows simultaneous power recovery of gauge and osmotic pressure and yields higher power than that yielded by the two processed applied separately.

Fig. 1 shows a typical SWRO desalination process that uses seawater as a source for the production of drinking water.

Prior to entering the SWRO desalination process, seawater undergoes intensive filtration to remove practically all suspended solids. Mediterranean seawater, used in our example, has 4% salinity and an osmotic pressure of approximately 30 bar.

Seawater is pressurized to a gauge pressure of approximately 62 bar by a high pressure pump and passes along several RO membranes located in the pressure vessels from the feed entrance to the brine outlet. As the seawater moves along the feed side of the membranes, about 50% of the seawater penetrates the RO membranes and becomes desalinated product (permeate), and the residual 50% exits the pressure vessels. This residual stream has a high salt concentration (8% salinity), twice that of the feed seawater, and an osmotic pressure of approximately 60 bar. As the feed flows through the pressure vessels, the gauge pressure drops slightly by 1.5% and remains at approximately 60 bar.

The brine stream produced at the outlet of the SWRO plant has four features that are important for recovery of osmotic power:

- The brine stream is clean of suspended solids as it was intensively treated prior to SWRO desalination.
- The salinity of the brine stream increased from 4% to 8%, increasing the osmotic pressure from 30 bar to 60 bar.

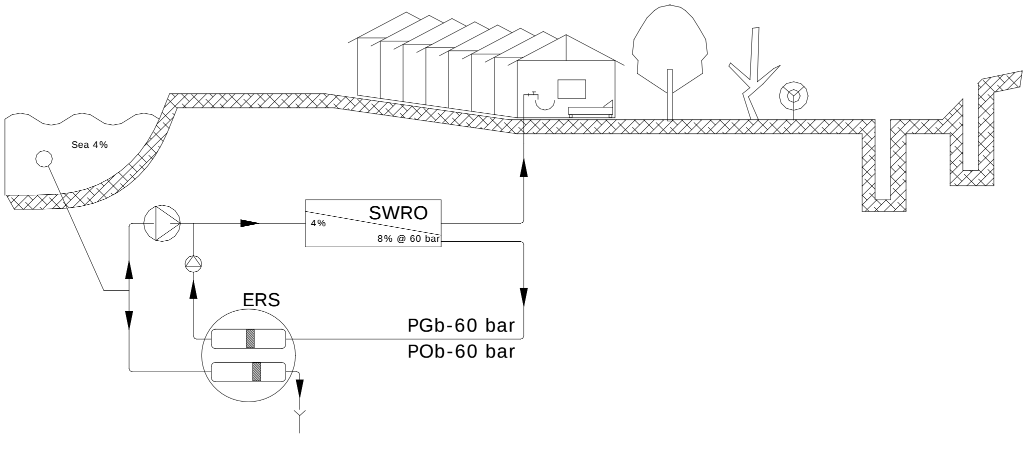


Fig. 1. Typical SWRO desalination process.

- The brine stream is pressurized to approximately 60 bar, as minimal pressure was lost through the pressure vessels.
- There are no additional costs related to the brine stream after the removal of the gauge pressure.

Note: the first two above-mentioned items are not pre-requisites for the process of gauge pressure recovery. Gauge pressure can be recovered using different methods, however for the purposes of this paper we will discuss the most advanced method, i.e. DWEER or ERI work exchangers. These work exchangers are basically reciprocal pumping devices that are filled with low pressure seawater in the first stage of the cycle and pressurized by high brine pressure in the second stage.

A low pressure circulation pump is used to compensate for losses in pipelines and pressure vessels. This process has a high efficiency of 96% for power transportation from the brine to the seawater feed stream.

To provide osmotic power recovery, a second liquid, with low osmotic and gauge pressure, is required in addition to the high osmotic and high gauge pressure stream (SWRO brine). This second stream must be clean of suspended solids and low cost, and can come from wastewater (WW).

2. Wastewater and membrane bio reactors (MBR)

Today wastewater can be treated in membrane bio reactors (MBR). Fig. 2 shows a view of an SWRO desalination plant and WW treatment plant using MBR.

The following three features are important for the recovery of osmotic power:

- MBRs are efficient ultrafiltration membranes that remove all suspended solids from wastewater and provide water suitable for passing through RO membranes.
- The salinity of wastewater is low as it originates from drinking water.
- The cost of wastewater MBRs is relatively low.

The combination of the four conditions of seawater desalination and the three conditions of MBR treated wastewater provides the ability to recover both high osmotic pressure and high gauge pressure in the SWRO brine, and transfer this energy to pumping seawater to the SWRO system, thereby minimizing energy losses.

3. Transfer of SWRO brine to mechanical pumping power

In order to convert the high osmotic pressure of SWRO brine to mechanical power, there must be a contact, via semi-permeable membranes, between the brine stream and the low osmotic pressure MBR treated wastewater stream. This can be performed in a seawater direct osmosis unit (SWDO) (Fig. 3).

The semi-permeable membrane must have an inlet and outlet on both membrane sides. It can be a hollow fiber, tubular, or flat sheet RO membrane with an inlet and outlet on the its permeate side. This will allow wastewater to pass through the membrane, as well as allow wastewater residuals that did not penetrate the membrane to be removed at the outlet. The most important unsolved issue to date is the internal and external concentration polarization that, at this stage, prevents practical implementation of osmotic power recovery. We will set this unsolved issue aside for the moment in the hopes that it will be solved by the membrane manufacturers.

4. Calculation of possible pumping power generation

The use of an SWDO unit to convert SWRO brine osmotic pressure to pumping energy for an SWRO plant, via a work exchanger, is presented in Fig, 4. The SWRO brine

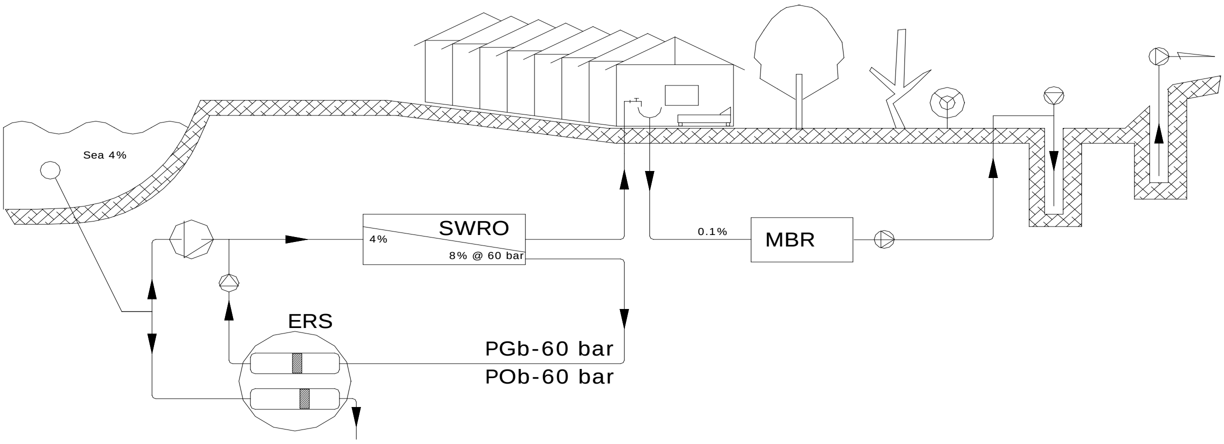


Fig. 2. SWRO and MBR.

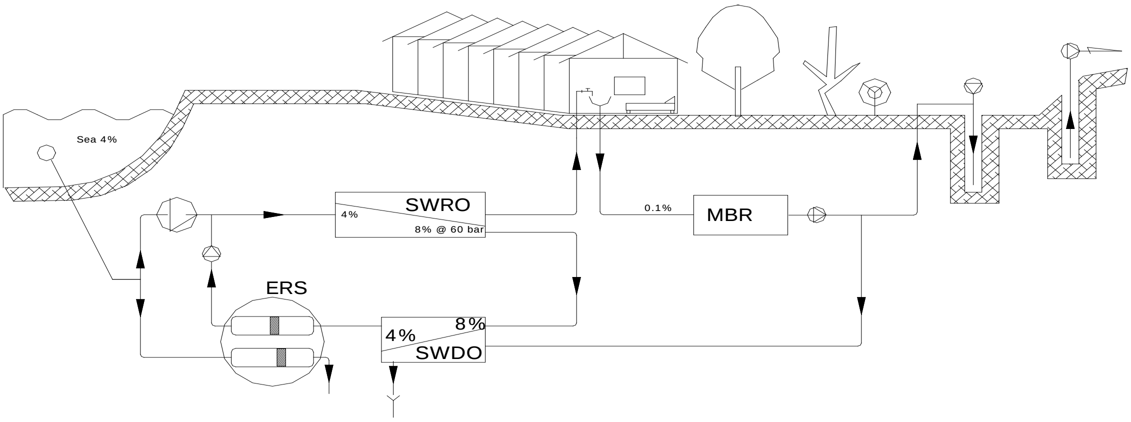
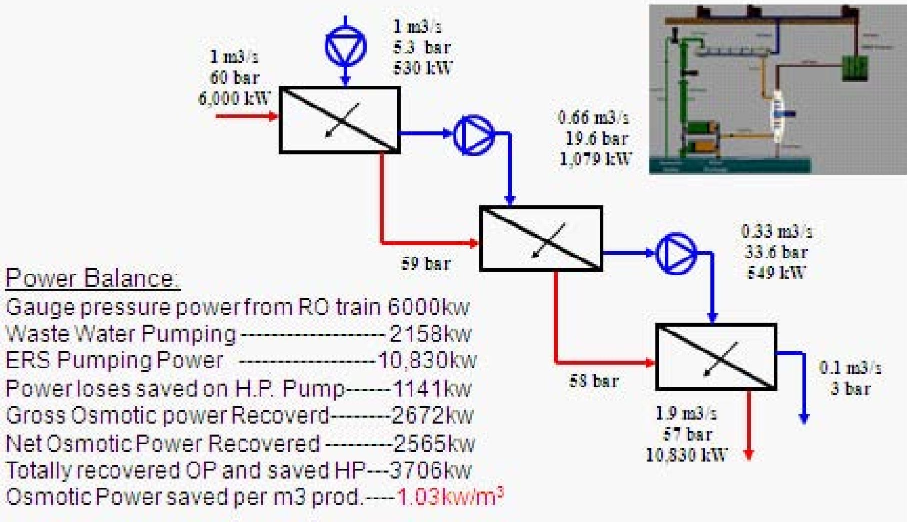


Fig. 3. SWRO and SWDO.



Power Balance:
Gauge pressure power from RO train 6000kw
Waste Water Pumping -------------------- 2158kw
ERS Pumping Power -------------------10,830kw
Power loses saved on H.P. Pump------1141kw
Gross Osmotic power Recoverd--------2672kw
Net Osmotic Power Recovered ---------2565kw
Totally recovered OP and saved HP---3706kw
Osmotic Power saved per m3 prod.----1.03kw/m^3

Fig. 4. Power saving calculation “Osmotic power recovery”.

lines are shown in red. A wastewater stream pumped into the SWDO unit is shown in blue lines. For the purposes of this calculation the following was considered:

- 1 m^3/s of SWRO brine, with gauge pressure of 60 bar; in other words, 6000 kW power from the desalination process and osmotic pressure of 60 bar.
- 1 m^3/s wastewater stream with 0.3 bar osmotic pressure and zero bar gauge pressure.

Osmotic power is recovered in four stages of the SWDO system and wastewater, with different pressures, is pumped into each stage to compensate for SWRO osmotic power brine losses due to dilution in previous stages. Furthermore, the fact was taken into account that in the new scheme a high pressure pump will reduce the capacity from 1 m^3/s to 0.1 m^3/s, thus saving the power losses associated with its inefficiency.

If we do not take into account the losses related to polarization, the osmotic power can be recovered as 1.03 kWh/m^3 of desalinated seawater.

Recovery of osmotic pressure must be made by high fluxes in order to maintain low capital expenses of the SWDO. This high flux operation requires an effective membrane cleaning method. This paper presents a direct osmosis high salinity (DO-HS) membrane cleaning technology that offers a new approach for keeping membranes clean continually using a frequent and short membrane backwash. RO membranes can be backwashed on-line once a day, without stopping the high pressure pump or decreasing the RO separation pressure. The injection of an NaCl solution for a few seconds redirects the process from RO to DO, and within 1 min the membranes are cleaned and the process returns to RO production.

5. How it works (physics)

In an RO process, a pump supplies pressure to the membranes, higher than the osmotic pressure of feed water. A short-time injection of a high osmotic pressure solution into the feed water provides a wave of process changes along the RO membranes, from the reverse to the direct osmosis, and permeates the backwash stream through the membranes.

The force required for the direct osmosis–high salinity (DO-HS) cleaning process can be provided by non-super saturated 26% NaCl solution, with osmotic pressure of 194 bar. A very small amount of high salinity solution is required for cleaning.

6. How it works in the RO plant

Simple mechanical changes are required for the implementation of this cleaning method.

The existing cleaning pump, tank and micronics filter of the CIP system are sufficient for the cleaning process.

7. Lifting and sweeping of fouling

Where the HS solution makes contact with the membrane, the permeate changes direction and moves from the low pressure permeate channel to the high pressure feed channel, lifting up the fouling and/or scaling components from the membrane feed surface. The permeate moves against the gauge pressure gradient.

The high salinity solution, with the foulants lifted from the membrane surface, moves with increasing velocity in the pressure vessel in the direction of the brine outlet like a purifying wave.

This increase in velocity takes place due to the fact that no permeate is produced, and, on the contrary, there is suction-up permeate in the places where the HS solution flows. The combination of feed-brine increased velocity with permeate lift-up velocity provides a strong cleaning effect. The osmotic pressure of the high salinity solution decreases along the way, but remains strong enough to create back permeate flow and lift foulants until it reaches the end of the pressure vessel.

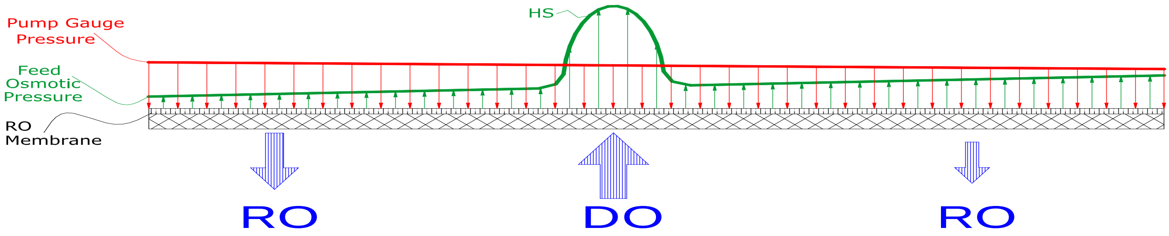


Fig. 5.

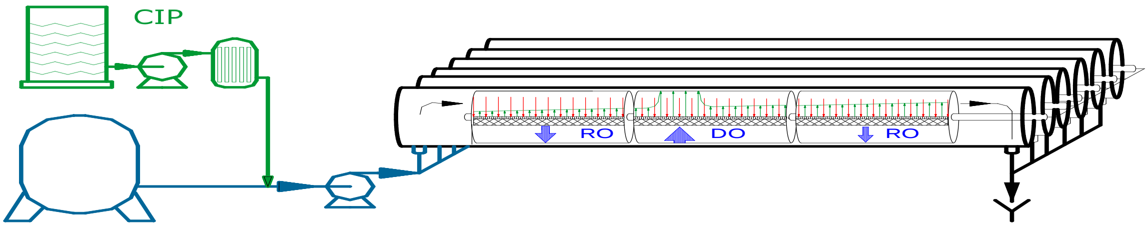


Fig. 6.

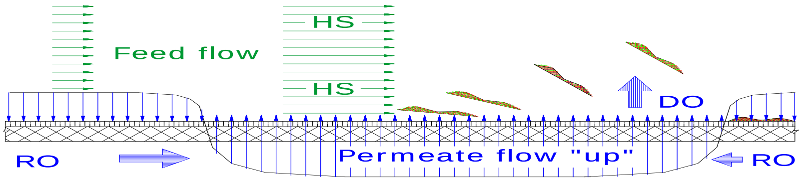


Fig. 7.

8. Bio-osmotic shock

A semi-permeable cell membrane, similar to the reverse osmosis membrane, covers the cytoplasm of organisms such as bacteria, algae, and fungi.

The HS solution sucks water up from the bacteria's cytoplasm as well as from the permeate channel of the RO membrane. The cell membrane shrinks and detaches from the cell wall, which is rigid and does not shrink. Separation of the cell membrane from the cell wall is fatal for bacteria, algae and fungi. This is the oldest sterilization method.

9. Changing philosophy of an RO plant operation

The DO-HS cleaning method offers a novel approach for reliable operation of the RO membrane, which is kept continuously clean by preventive, short and frequent membrane backwash. The DO-HS process is an on-line technique without interruption of the operational process, unlike a widely used CIP technique that requires shut-down of an operational train in order to cleam the membrane, as well as disposal of aggressive solutions.

DO-HS cleaning is both environmentally- and membrane-friendly, and is performed on-line, at a low cost. The process can easily be applied to an operating facility as well as to a newly-designed project.

10. Membrane integrity

Membrane manufacturers such DOW, Hydranautics and Toray have tested and approved DO-HS membrane cleaning technology for implementation. Koch have approved the implementation of DO-HS cleaning technology based on actual implementation in the Dshanim Factory, Israel. This DO-HS membrane cleaning technology has been in commercial operation since 2005 on all above-mentioned RO membranes in several desalination plants.

11. DO-HS cleaning successfully implemented

The Dshanim factory in Israel has been performing DO-HS cleaning in four containerized brackish water RO trains since 2005, and on two new RO plants since 2007. The RO plant operates with a combination of KOCH, Hydranautics and DOW membranes. Within 50 days of daily DO-HS treatment, the bio-fouling was removed, and there was a significant decrease in the pressure drop and the permeate conductivity.

Sixteen membranes were weighed before and after DO-HS cleaning. Their weight decreased from 20–23 kg before cleaning to approximately 17 kg thereafter. Membranes have not been replaced in these RO trains since the start of DO-HS treatment.

Blue & Green BWRO (Israel) Plant applies DO-HS cleaning in two RO trains operating with old DOW Filmtec membranes. The raw feed comes from heavily fouled shallow wells, including 0.06 ppm oil. Pretreatment consists of a 5 micron cartridge filter only. Prior to implementation of DO-HS treatment the plant was cleaned weekly using a conventional CIP procedure. Within 2 weeks of DO-HS treatment, performed 4 times a day, DP decreased from 6.5 to 3.4 bar. Conductivity decreased from 815 μS to 437 μS. No conventional CIP was carried out during the DO-HS treatment.

DO-HS is an environmentally friendly, preventive technique that is performed on-line, at low cost, without interruption of the RO process. This allows continuous production of water and brings significant benefits to the overall reverse osmosis system performance.

The process can easily be applied to an already-operational facility, as well be designed for a new project.

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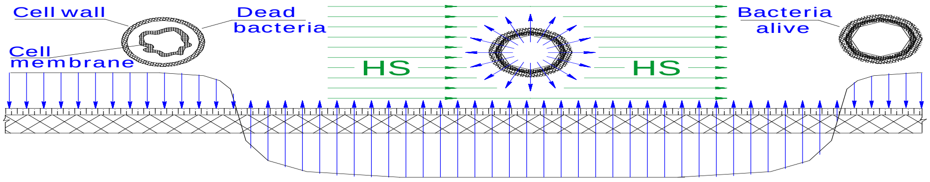

Fig. 8.

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