RECOVERY OF OSMOTIC POWER IN SWRO PLANTS

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Abstract

For the last two decades the attention of companies leading the desalination market has been focused mainly on energy saving. Almost half of the energy invested in the seawater desalination process is now recovered. The process of recovering gauge pressure from SWRO desalination plants started 20 years ago using the Pelton wheel has now reached 95-96% efficiency using DWEER and ERI work exchangers. In parallel, the brine of seawater RO plants contains “green fuel” in the form of high osmotic pressure that goes to waste in the brine discharge to the sea.

The theoretical possibility of recovering osmotic pressure as mechanical work power was developed by Prof. Sidney Loeb 35 years ago. This theoretical value is 1.55 kwh per cubic meter of desalinated seawater.

To date the industry has not found a practical way to recover the osmotic pressure presence in SWRO brine. The main obstacle to this is the phenomenon of Concentration Polarization (CP), of which there are several types: Internal Dilutive (IDCP), External Concentrative (ECCP), Internal Concentrative (ICCP) and External Dilutive (EDCP). This paper presents an analysis of these types of CP, depending on the position at which draw and feed solutions move and relative to the location of the support and rejection layers.

CP takes approximately 95% of the Net Driving Forces theoretically available for osmotic power recovery. With the existing technology and RO membranes on the market, only 5% of osmotic power can be recovered. This 5 % does not cover the expenses of the process, and for this reason remains unused.

The paper analyzes the ways that different researchers have selected to overcome the phenomenon of CP, and presents an overview of the existing RO membranes from the point of view of their suitability for use in Forward Osmosis power generation.

Furthermore, the paper presents recommendations to membrane manufactures.

Finally, the paper introduces a way that allows the simultaneous power recovery of gauge and osmotic pressure, which gives a higher power yield than the two processes applied separately.

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In the 1970s, Sidney Loeb patented a process for converting osmotic potential-energy into electrical energy. Known as Pressure Retarded Osmosis ("PRO"), this is essentially a forward osmosis process.

A semi-permeable membrane separates two solutions with different osmotic and hydrostatic pressures. Water moves from the low to the high osmotic side of the membrane, against the hydrostatic pressure gradient, resulting in an excess volume of diluted and hydrostatic pressurized seawater. This additional volume of hydrostatic, pressurized, high osmotic water is used for power generation in different forms. From the energy balance point of view the osmotic pressure by is replaced by hydrostatic pressure.

There is a significant research and development effort underway by the Norwegian utility company, Statkraft, to develop a cost effective PRO process. River water penetrates into hydrostatic pressurized seawater via an RO membrane, and this additional water volume generates power. A pilot plant was built near Oslo to generate 4 kilowatts of power with approximately 2,000 m2 of membranes.

River water has low osmotic pressure, below 0.3 bars, as well as low gauge pressure. Seawater is pumped up to a gauge pressure of about 14 bars, which is equal to half of its natural osmotic pressure. Energy from the additional volume can be recovered with a hydraulic turbine and converted to electricity using an electric generator.
The main obstacles in the way of a cost effective PRO process are: Internal and External Concentration Polarization (ICP-ECP), absence of suitable PRO membranes and membrane fouling.

Concentration polarization is a well known problem in RO membrane desalination, decreasing permeate flow due to increased osmotic pressure on the feed side of the membrane. Asymmetric membranes are sued in the RO and PRO processes.

In PRO processes concentration polarization occurs on both sides of the membrane with a significantly greater negative effect, making the entire PRO process not cost effective. In the PRO process active or salt rejection layer feces high pressure, draw solution side and porous support layer faces low pressure permeate side. In PRO process dilutive External Concentration Polarisation ("ECP") occurs at the active layer surface and Internal Concentration Polarisation ("ICP") occurs within the porous support layer of the membrane. ICP plays a prominent role in reducing the effective trans-membrane osmotic pressure.

Fig 1 presents schematically ICP and ECP processes.

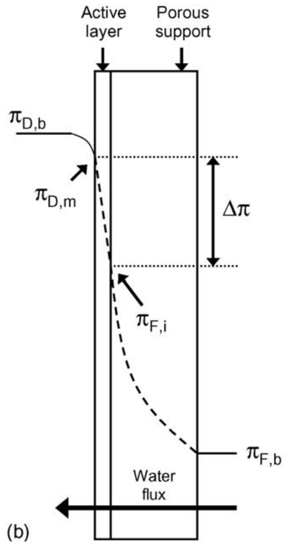

Figure 1 – ICP and ECP processes.

Some of researchers see the way to diminish ICP in request to membrane manufactures to development new PRO membranes with thin support layer. But thin support layer is not able to withstand the hydrostatic pressure difference that PRO process requires. This contradiction: *to be thin but at the same time withstanding the hydrostatic pressure difference along the membrane layer* makes this problem unsolvable by mechanical means by membrane manufactures.

The ICP problem can be solved by technological means (IDE's Patent Pending) via washing away concentrated salt from support layer by periodical substitution of PRO process by RO process for short time.
This technology has some similarity with UF membrane backwash. The difference from UF backwash is source of driving force. In UF backwash driving force comes from changing hydrostatic pressure gradient between feed and filtrate side. In PRO-RO process backwash driving force comes from changing osmotic pressure. Fig 2 presents osmotic and gauge pressure forces that determinate water movement in PRO and RO processes.

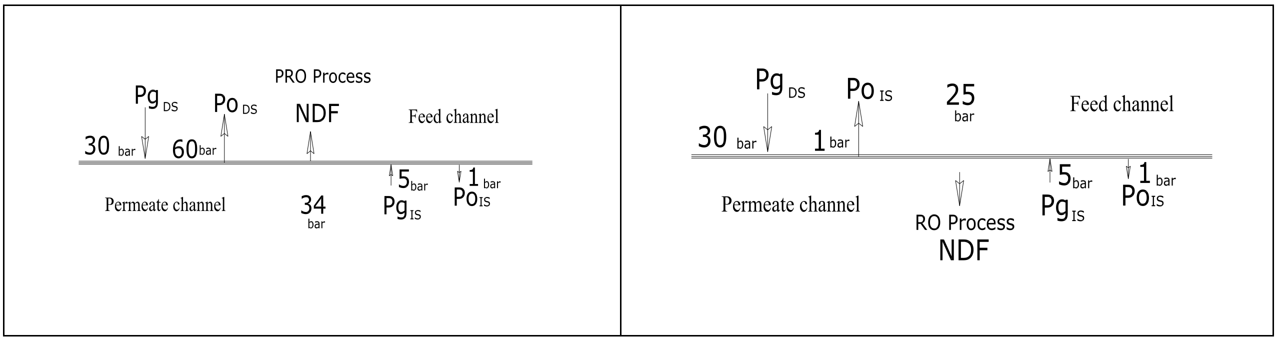

Figure 2 – Forces in PRO and RO

The PRO-RO process presented in this paper based on SWRO brine as draw or "Hypertonic Solution" (HrS) and MBR treated waste water as "Hypotonic Solution" (HoS). HoS moves in to HrS during PRO process and HoS replaces HrS during RO process.

Numerical example of PRO and RO processes.

HrS has high osmotic pressure POd and is fed under high gauge (hydrostatic) pressure PGd. HoS has low osmotic pressure POi and has low gauge pressure PGi. The PRO and RO process is driven by the balance of all the above pressures, herein called Net Driving Pressure (NDP).
NDP (PRO/RO) = PGd – POd – PGi + POi

When the NDP is negative, the PRO process takes place and HoS moves from permeate side in to feed side dilutes HrS and increases it volume.

Exemplary values for a PRO:
NDP (PRO) = 30 – 60 – 5 + 1 = -34 bar

The NDP became positive, when HoS replaces HrS for about 30 second on the both sides of membrane located the same low osmotic pressure HoS. The process becomes RO and it is driven by difference of gauge pressures only.
Exemplary values for a RO:
NDP (RO) = 30 – 1 – 5 + 1 = +25 bar.

The graphical form PRO-RO technological shown in Fig -3

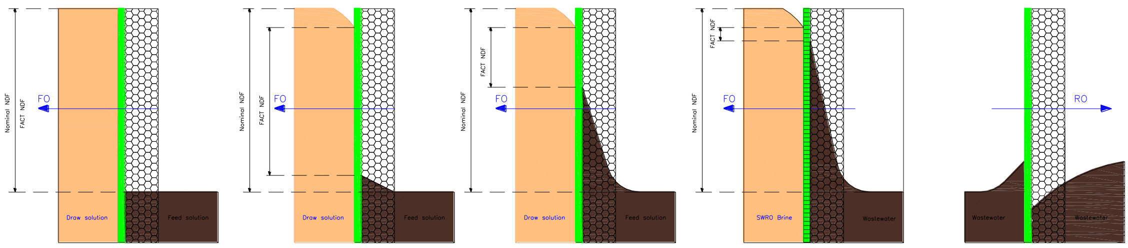

Figure 3 – PRO-RO process

The first four schemes on Fig 3 present PRO process where ICP process develops. It can be seen that NDF diminished during PRO process. The fiftieth scheme presented the RO process that take place when HoS replaces HrS for short period.

A pilot was build to test effectiveness of this PRO/RO process. Fig-4

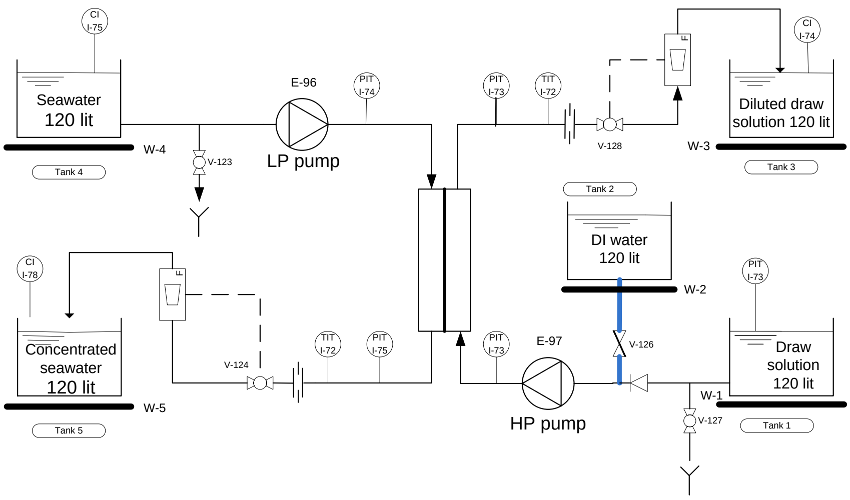

Figure 4 – PRO-RO pilot.

Pilot includes four 120 liter tanks installed on electronic scales connected to computer. Standard Filmtec reverse osmosis membrane element TW30-2514 was used in this test. Rubber plug was installed in the middle of permeate tube allow water pass throw permeate spacer. HP pump installed to pass 7.7% NaCl HrS via normal feed connection of membrane. LP pump installed to pass 0.1% NaCl HoS to first half of permeate tube till rubber plug. HoS enters permeate spacer via several 2 mm openings, passes part of permeate spacer and went out via second part of openings in permeate tube.

It was recognized that distribution of HoS along permeate spacer was not even.
2nd 120 liter tank with HoS, was installed with possibility to replace HrS by HoS in the suction site of HP pump. Because 2nd HoS tank positioned higher then HrS tank opening of Valve HV-1 provide full replacement of HrS by HoS. Fluxes were calculated based on mass of liquid added or withdrawal from the tanks on the scales.
The first goal of research was measure the rate of ICP-ECP process increase with time. The process approach was selected in such way that HP and LP pumps are working non-stop. The only one change was done; the HV-1 valve was open or closed. When HV-1 valve was closed HP pump pass to feed of membrane HrS and PRO process take place. When HV-1 valve was open HP pump pass to feed HoS, and RO process take place.

<u>Observation of ICP-ECP process development during long time PRO process that take place after short RO back flush.</u>

Initial fluxes observed during first few second of PRO process have high values about 40 lmh. See Fig-5.

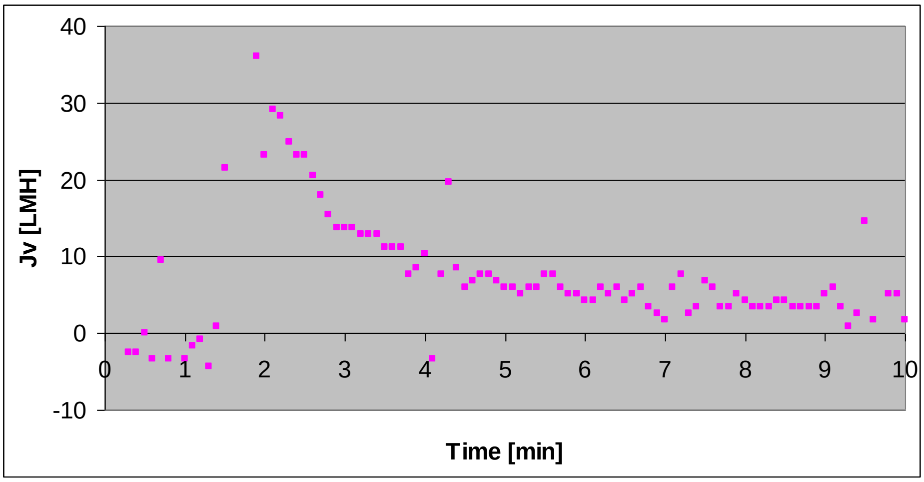

Figure-5 – PRO Fluxes during first ten minutes.

The full development of ICP-ECP process within PRO takes about ten minutes. It starts from about 40 lmh in first minute and stabilized on 2.5 lmh in ten minutes.

On Fig -6 presented PRO-RO process where 300 sec of PRO process was replaced by 30 seconds of RO.

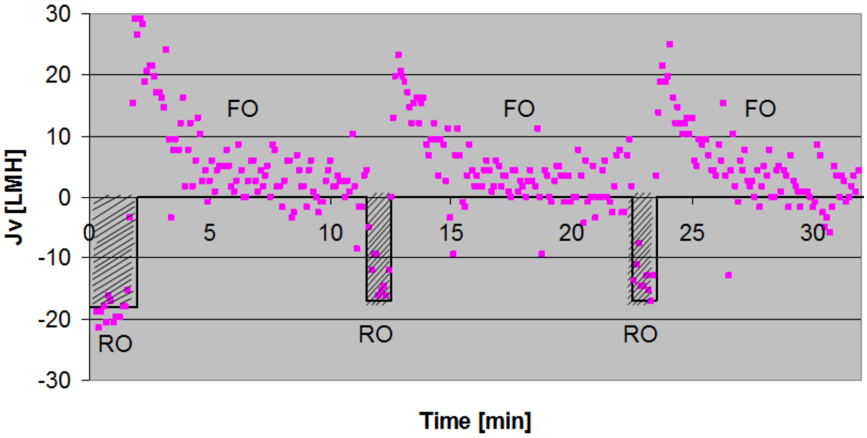

Figure 6 – Fluxes in PRO-RO process.

The ICP was flushed out by consecutive exchange of PRO process by RO process. The average fluxes of PRO- RO increased about five times from 2.5 LMH to 13 LMH.

A Design-Expert 6.0 software was used in order to find the best working points of PRO / RO processes for specific membrane that was tested.. This is a mathematical-statistical software enabling design of experiments and process optimization. After determining a set of parameters and their range (such as time, flow rate, pressure etc.), the software provides a set of experiments. After conducting these experiments and feeding the main results (such as flux, energy density etc.) the software provides numerical and graphical analysis of the results, enabling to change the parameters range. Repetition of this process leads to finding the optimal working conditions.

The best results were achieved while conducting a series of experiments in which the PRO time was 120-200 sec, the RO time was 25-40 sec, The optimum of PRO-RO process for specific DOW membrane [TW-30-2514] presented in Fig 7.

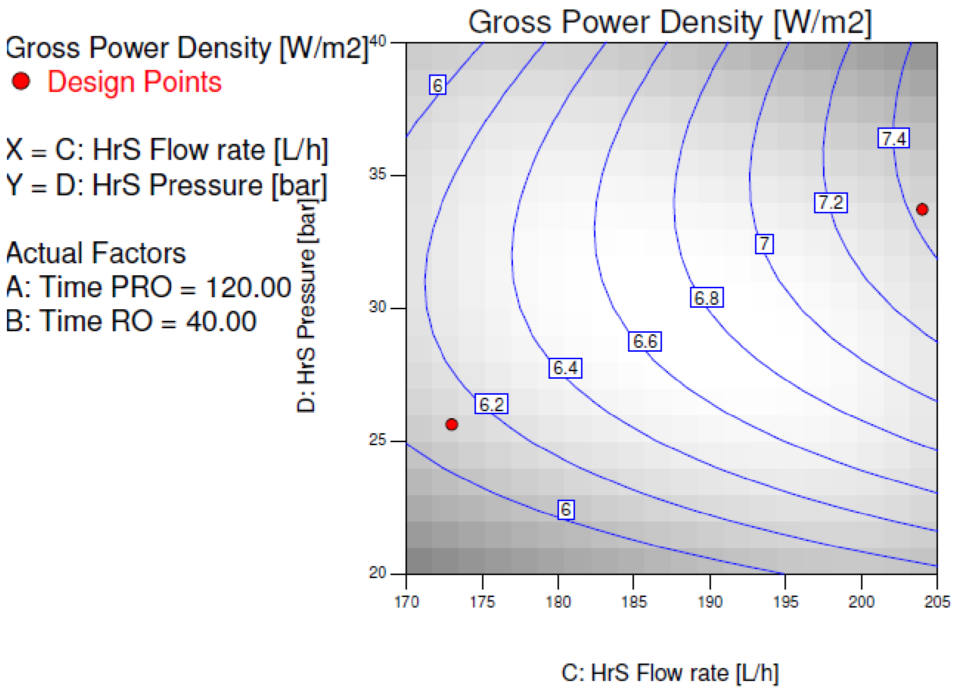

Figure 7 – Gross power density in PRO-RO process.