

# **Brine Discharge Procedures to Minimize the Environmental Impact and Energy Consumption**

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## **Abstract**

Brine discharge has become one of the latest concerns for authorities worldwide that have implanted environmental policies in order to preserve biodiversity. Focusing on the Spanish case, Posidonia meadows can only be found in the Mediterranean Sea, and are actually protected by European Community. Because of the importance of Posidonia meadows, the use of brine discharge procedures in order to minimize the environmental impact have become more and more important in Spain. We'll show brine discharge procedures for helping not only to minimize the environmental impact but to minimize energy consumption of the desalination plant.

## **I. INTRODUCTION**

One of the main concerns of the Spanish government for desalination plants is how to minimize the environmental impact during inflow of sea water to the desalination plant and the outflow of brine from the desalination plant.

In order to design the brine discharge, we are going to focus on the steps that we should take for a correct design:

1. Nowadays, there are several kinds of brine discharge procedures that have proven their effectiveness in desalination plants. So, we can take advantage of well-known technology on this subject, but we've got to ask ourselves why those procedures are so effective.
2. What's more, the appearance of new energy recovery devices (ERD) have changed not only the way to design the desalination plant, but have also opened new alternatives that can be used to optimize the brine discharge procedure.
3. On the other hand, it seems important to develop a mathematical model that includes every single variable known. As we already have proven [1], the usual mathematical models employed for brine discharge don't consider the direct osmosis effect in their equations.

The current paper will show how these three steps are closely related and how we should take into account every one of them for an accurate brine discharge design.

## **II. RESEARCH CONDUCTION**

As we have mentioned before, desalination plants in Spain are already employing different procedures in order to minimize the environmental impact. One of the main procedures is to employ diffusion nozzles at the end of the brine discharge pipe. First of all, we should ask ourselves why this procedure is so effective.

Diffusion nozzles show two main characteristics:

1. Diffusion nozzles increase the active area between brine and sea water
2. Diffusion increases with the time of contact between brine and sea water.

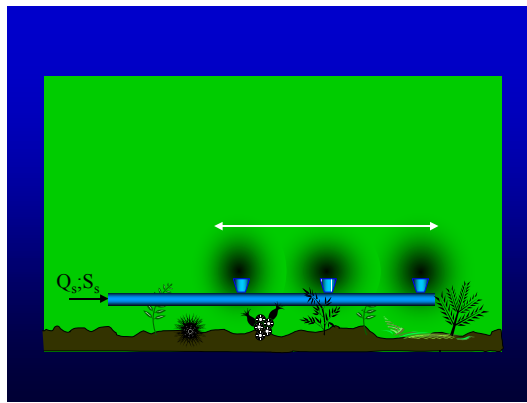
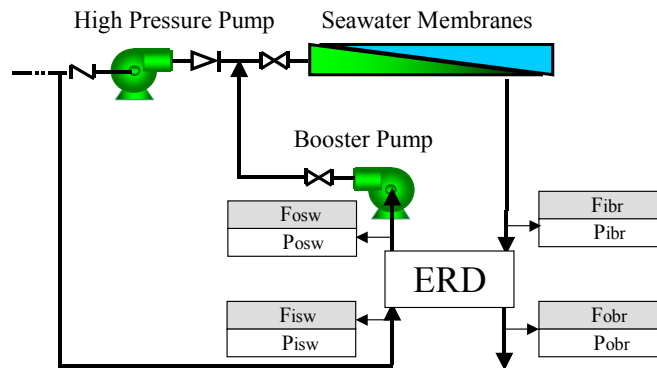


Figure1. Example of diffusion nozzles

At the same time, both effects can be amplified by increasing outlet brine pressure. The new ERD can be used for this purpose. What are the main characteristics of these new energy recovery devices? As shown in the following figure, the brine pressure to discharge can be easily chosen by the designer. The rest of design parameters for desalination plant are calculated based on this pressure.



Where:

- P<sub>ibr</sub> – Brine pressure from membranes
- P<sub>obr</sub> – Brine pressure to discharge
- P<sub>isw</sub>– Sea water inlet pressure
- P<sub>osw</sub> – Sea water outlet pressure

Figure 2. Inverse Osmosis Plant (Flux Diagram)

ERD manufacturers supply information about pressure loss in both sides of their equipments: the high pressure side ( $\Delta p_2$ ) and the low pressure side ( $\Delta p_3$ ).

$P_{ibr}$  is known and it depends on membrane input pressure  $P_{swm}$  and pressure loss from membrane input to ERD input ( $\Delta p_1$ ), (1).

$$P_{ibr} = P_{swm} - \Delta p_1 \quad (1)$$

$P_{isw}$  is known and it can depend on minimum pressure requirement at ERD input for sea water or it can be decided by the designer as it depends on other system characteristics.

Now we can calculate  $P_{obr}$ , see (2) and  $P_{osw}$ , see (3).

$$P_{obr} = P_{isw} - \Delta p_3 \quad (2)$$

$$P_{osw} = P_{ibr} - \Delta p_2 \quad (3)$$

There is one more ERD requirement, the minimum pressure at ERD output of brine ( $P_{minobr}$ ). We must verify that  $P_{obr} > P_{minobr}$ .

As we know, there are several phenomenons that occur during the brine discharge:

1. Dispersion
2. Diffusion
3. Difference of density

All of them, are highly studied on the mathematical models and they affect one way or another brine diffusion. As we said before, none of the mathematical models take into account the direct osmosis effect. If we focus only on the direct osmosis phenomena for modeling the brine discharge, we have the following figure:

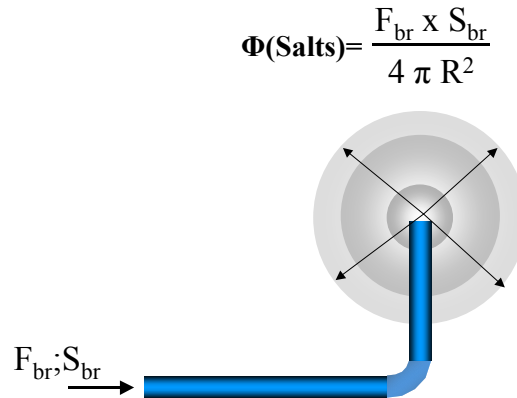


Figure 3. Salt Flux

As shown in the figure, the Salt Net Flux through a concentric sphere is (4):

$$\Phi(\text{Salts}) = \frac{F_{br} \times S_{br}}{4 \pi R^2} \quad (4)$$

The divergence of the salt net flux is zero for any closed sphere, since the brine that flows into the sphere must flow out again (5). We can therefore find a scalar field at which Laplacian is zero. This scalar field is the salt concentration in every concentric sphere.

$$\text{div } \vec{\Phi} = \frac{\partial \Phi}{\partial R} + \frac{2}{R} \Phi = \frac{F_{br} \times S_{br}}{4\pi} \left( \frac{-2R}{R^4} + \frac{2}{R^2} \frac{1}{R} \right) = 0 \quad (5)$$

According to our hypothesis, the gradient of this scalar field depends on the osmotic pressure.

The boundary conditions are:

$$\begin{aligned} \Delta S &= 0 \\ S(R = 0) &= S_{br} \\ S(R = \infty) &= S_{br} \end{aligned} \quad (6)$$

Resolving this equation system for each particular case, we'll have a equilibrium situation for the direct osmosis effect.

As an example, we have modeled brine discharge by diffusion nozzles for a desalination plant with the following characteristics:

- Total Production = 120.000 m<sup>3</sup>/day
- Conversion Factor = 47%
- Brine Flow to discharge= 135.319,15 m<sup>3</sup>/day=5.639,3 m<sup>3</sup>/hour
- Sea water analysis as follow.

SEA WATER ANALYSIS					
TURBITY	1,75	U.N.F.	pH	8,05	
COLOUR	1,53	Pt-Co	CONDUCTIVITY	54.408,89	µmhos/cm
TEMPERATURE	18	°C	T.D.S.	39.338,36	mg/l
			ALCALINITY	149,79	ppm CO <sub>3</sub> Ca
			TAC	6.420,07	ppm CO <sub>3</sub> Ca
SEA WATER IONIC COMPOSITION					
ELEMENT	Mg/l	Meq/l	ELEMENT	Mg/l	Meq/l
Ca <sup>++</sup>	465,45	23,23	SO <sub>4</sub> <sup>=</sup>	3.049,00	63,48
Mg <sup>++</sup>	1.278,94	105,21	Cl <sup>-</sup>	21.589,37	608,96
Na <sup>++</sup>	12.285,62	534,37	CO <sub>3</sub> H <sup>-</sup>	157,98	2,59
K <sup>+</sup>	487,89	12,48	F <sup>-</sup>	1,37	0,07
Ba <sup>++</sup>	0,01	0,00	Br <sup>-</sup>	0,00	0,00
Sr <sup>++</sup>	5,12	0,12	I <sup>-</sup>	0,00	0,00
Fe <sup>++</sup>	0,00	0,00	NO <sub>2</sub> <sup>-</sup>	0,00	0,00
NH <sub>4</sub> <sup>+</sup>	0,01	0,00	NO <sub>3</sub> <sup>-</sup>	0,00	0,00
Ag <sup>+</sup>	0,00	0,00	CO <sub>3</sub> <sup>=</sup>	12,12	0,40
Mn <sup>++</sup>	0,00	0,00	PO <sub>4</sub> <sup>=</sup>	0,00	0,00
Zn <sup>++</sup>	0,00	0,00	S <sup>=</sup>	0,00	0,00
Cu <sup>++</sup>	0,00	0,00	SiO <sub>2</sub> (colloidal)	25,42	0,42
Al <sup>+++</sup>	1,00	0,11	SiO <sub>2</sub> (soluble)	0,26	0,00
Fe <sup>+++</sup>	0,00	0,00	CO <sub>2</sub>	1,04	0,02
H <sup>+</sup>		0,00	OH <sup>-</sup>		0,00
TOTAL	14.524,04	675,51		24.810,10	675,51

Figure 4. Sea water analysis

### III. RESULTS

The results are shown in the following figure. The brine concentration on the seafloor at 6 m distance from diffusion nozzles discharge is 40.830 ppm over 39.338,36 ppm of the sea water.

Nominal production	120.000 m3/day
Brine flow	5.638,3 m3/h
Brine discharge pressure	0,66 bars
Number of diffusion nozzles	3 Units
Diffusion nozzle area	723,53 cm2
Diffusion nozzle diameter	30,35 cm
Brine output speed	7,22 m/s
Diffusion nozzle angle	45°
Pipe height over seafloor	2 m
Brine concentration on the seafloor	40.830 ppm

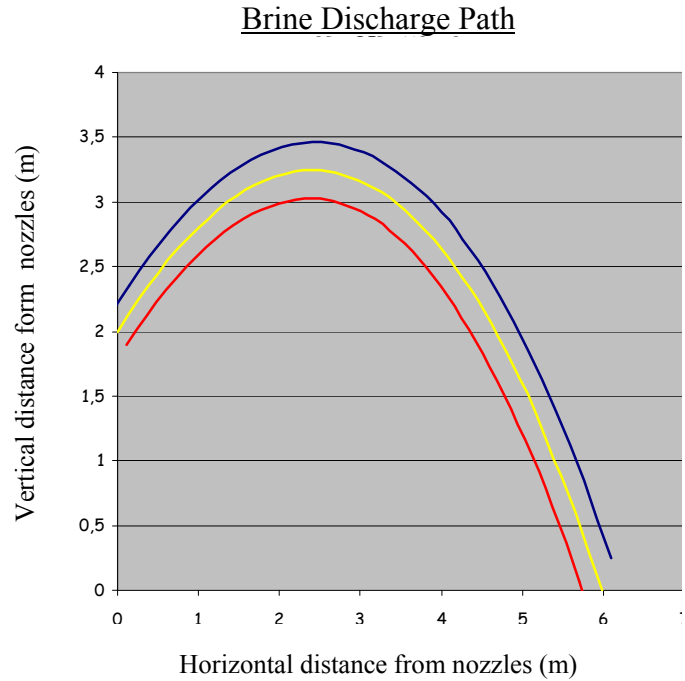


Figure 5. Brine discharge

### IV. CONCLUSIONS

A proper desalination plant design can minimize the environmental effect by reducing TDS around the discharge point. It is specially interesting that the direct osmosis effect for brine discharge, in the studied case and over 6 m distance from diffusion nozzles discharge, the brine TDS is almost the same as sea water TDS. The new ERD can be used to intensify the direct osmosis effect by increasing ERD outlet brine pressure.

### V. LITERATURE CITED

1. J.M. Sánchez. *El fenómeno de la Osmosis en la dispersión de la salmuera en un lecho marino*. Jornada Científica: Plantas desaladoras y vertido marino, organizado por I.E.H., Aguas de la Cuenca del Segura y AEDyR. Murcia (Spain). 2003.