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Concentrate and other waste disposals from SWRO plants: characterization and reduction of their environmental impact

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Abstract

The purpose of this paper is to characterize the various discharge from SWRO plants, and to review all the solutions allowing to reduce their impact on the environment. This approach to obtain high environmental quality plants involves not only new desalination plant projects, but also those already in operation. This high environmental quality plants approach involves new desalination plant projects, as well as those existing. By searching for the best solutions to protect the environment, operating costs can be quite often subsequently improved.

Keywords: Desalination; Reverse osmosis; Seawater; Discharge; Environmental impact; High environmental quality

1. Introduction

Due to the multiplication of desalination plants worldwide, as well as an increase in their production capacity and, therefore, their discharge volume, their impact on the environment can no longer be neglected.

It is not the intention of the authors to describe here the effects of discharge from desalination plants on the fauna, flora and sea bottoms, but rather to review all the elements capable of contributing to a better environmental control and management of the flows returning to the sea.

Searching the environment protection, can also have positive repercussions on the SWRO operation costs.

This twofold challenge—environmental and economic—must persuade promoters of desalination plants to ask all kinds of

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questions right from the initial phases of the design:

- Have we selected a suitable site?
- Do we know all the environmental constraints and requirements of the site?
- Can we improve the physical-chemical characteristics of the discharges by impacting on the process?
- What are the resources to be implemented to reduce the impact of the discharges on the marine environment?
- How to proceed for discharge disposal?

Other questions may also be raised involving those elements having impacts outside of the plant's immediate environment, such as how to reduce the electric energy consumption? Any reduction in the installed power needed for the production of fresh water will have a direct repercussion on the environmental impact of the power station which is dedicated, totally or partially, to the desalination plant: reduction in the volume of cooling water, rejects in the atmosphere, and so on.

2. Effluents: nature and quantity

The effluents from SWRO result essentially from:

1) physical pretreatments: backwash water from filtration units;

2) reverse osmosis lines: concentrate, rinsing water;

3) membrane cleaning units: dirty chemical solutions.

These effluents are characterized:

- for the first ones, by the high loads of suspended solids containing biological, mineral and organic matters;
- for the second ones, regarding the concentrate, by a high content in dissolved salts (generally from 1.7 to 2.5 times that of the seawater content) and by an acid pH (pH about 5.50 vs. a seawater pH close to 8.00). The concentrate salinity is given by the following equation:

$$TSD_c = TDS_{sw}\left(\frac{1}{1-Y}\right) - \frac{Y \times DS_p}{100(1-Y)} \quad (1)$$

where TDS_c, concentrate salinity; TDS_{sw}, seawater salinity; TDS_p, permeate salinity; Y=recovery=permeate flow rate/feed flow rate.

By neglecting the permeate salinity, which is about 1% seawater salinity, Eq. 1 becomes:

$$TDS_c = TDS_{sw}\left(\frac{1}{1-Y}\right) \quad (2)$$

- for the third ones, by a pH that may be very alkaline (pH 11) or very acid (pH 3) and strong loads in biological, mineral and organic matters.

It should be noted that the rise in water temperature in the RO process is very low (about 1°C). On the contrary, thermal desalination process induces a rise between 3 and 18°C, according to the type of process and the initial temperature of the seawater.

With regard to the quantities of produced effluents

1) For the physical pretreatments, they vary from 2 to 10% of the seawater pumped, according to:

- the selected filtration process: filtration on granular materials (sand, anthracite+sand), microfiltration using washable elements, ultrafiltration;
- the microbiological, organic and physical-chemical characteristics of the seawater to be treated.

Example: Let's consider seawater having a suspended solids (SS) concentration of 10 mg/l. A dual media filtration unit (anthracite + sand) treating 100 m^3/h at a filtration rate of 10 m^3/h per m^2 will produce daily

75 m^3 of dirty water, corresponding to a loss of 3.1% with regard to the pumped flow rate. Neglecting SS in the filtered water, we can deduce that the SS concentration of the dirty washing waters is 32 times higher than the seawater SS content, that is to say about 320 mg/l.

For a micro or ultrafiltration pretreatment, backwash water can reach 5–10% of the pumped volume, that is, a higher quantity compared to granular media filters, but lower SS concentration;

2) The concentrate produced by the RO units vary from 40 to 60% of the feed flow rate according to the recovery. It is given by the following relationship:

$$Q_c = (1 - Y)Q_f \tag{3}$$

where: Q_c, concentrate flow rate; Q_f, feed flow rate; Y, recovery, expressed by the relationship

$$\frac{Q_f - Q_c}{Q_f} \tag{4}$$

The recovery value depends on:

- the number of elements installed in each pressure vessel;
- the number of passes;
- the number of stages per pass;
- the type of membranes used;
- the desired quality for the permeate.

The RO units discharge, in addition to the concentrate:

- at each start-up, pretreated water until the required quality is obtained (especially with respect to turbidity), as well as permeate until its conductivity matches to the required value;
- at each shutdown, rinsing water in order to reduce the salinity of the water contained in the concentrate zone of the membranes, so that the direct osmosis phenomenon is limited or avoided, since it might dry the membranes. This rinsing can be performed with seawater or permeate, each one containing, or not, a biocide such as sodium bisulfite.

As a result, we can see that it is very difficult to evaluate this type of discharge, quantitatively as well as qualitatively, due to:

- the nature of the fluids used;
- the number of start-up and shutdown.

3) Rejects from chemical cleanings mainly depend on the frequency of these cleanings. But it should be noted that they only involve low volumes compared to other effluents.

Fig. 1 illustrates what precedes concerning the various discharges of a SWRO plant.

3. Treatment of effluents before their discharge into the sea

3.1. Discharge 1 in Fig. 1

As indicated above, the backwash water, regardless of the filtering mode, presents high suspended solids content. According to the site's environmental constraints and requirements, it may be necessary to treat them before discharge.

The treatment can include a coagulation-flocculation followed by a clarification. For coagulation-flocculation, an anionic polymer is used. Flocculation is performed in a tank equipped with an adjustable low speed turbine, while the clarification is performed in a settling tank, of a lamellar type for instance. The treated water contains less than 10 mg/l of SS, which is quite similar to the seawater.

The sludge extracted from the settling tank may be thickened after an injection of polymer; it is dewatered on a belt filter, filter press, centrifuge or simple drying beds. The dewatered sludge is stored and then directed towards landfill or spread.

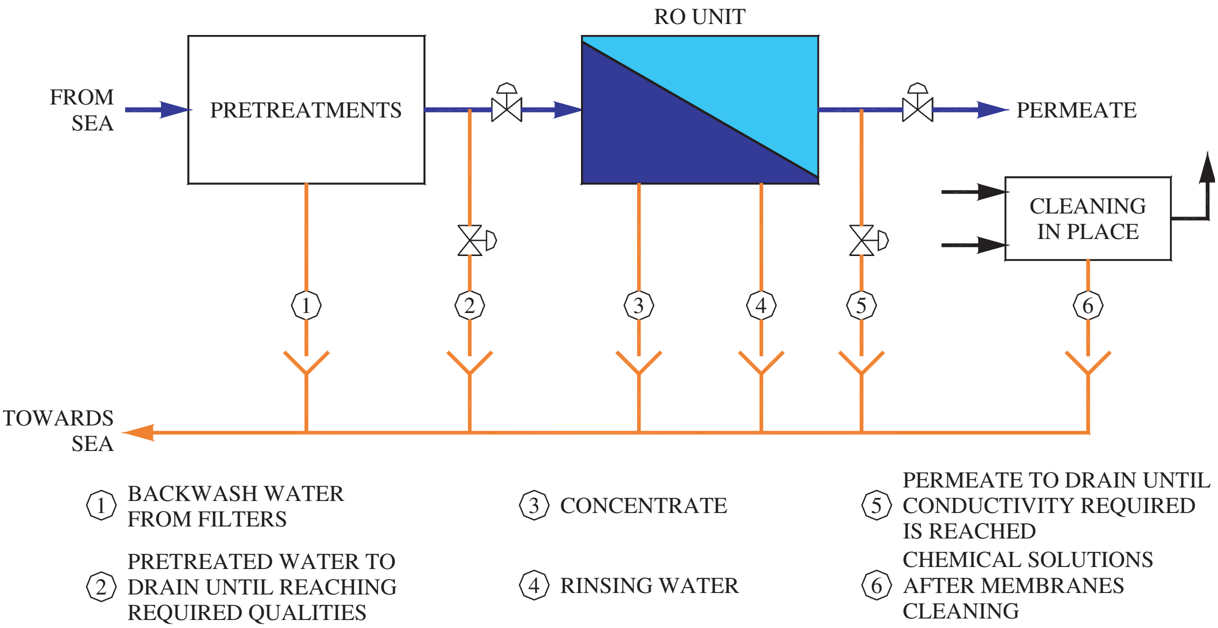

Fig. 1. Illustration of various discharges from SWRO plant.

Fig. 2 illustrates the effluent treatment process such as described above.

3.2. Discharge 2 in Fig. 1

This effluent does not require any special treatment because its salinity is identical to that of the seawater, its pH is in the vicinity of neutrality and it does not contain any harmful element to the marine fauna or flora.

When the seawater is chlorinated, the pretreated discharged water comes from a point located downstream the dechlorination unit.

3.3. Discharge 3 in Fig. 1

As seen above, the concentrate has a high salinity and a pH located in the acid range.

For some discharge areas having, for example coral reefs, the effluent pH must be not less than 8. Therefore, it is advisable to inject an alkalizing agent in the concentrate, like soda for example.

3.4. Discharge 4 in Fig. 1

If the rinsing waters are either pretreated seawater or permeate, and no biocide has been added, then the effluent can be discharged just as it is. If a biocide is injected, some precautions will have to be taken, described below in section 4.

3.5. Discharge 5 in Fig. 1

Normally, a discharged permeate of poor quality does not have any characteristics which would avoid it from being discharged directly to the sea. But in some cases it might happen that this effluent has a high biocide content, such as when it is made to a shock treatment by injection of sodium bisulfite. Just like for the discharge of rinsing water containing this product, some precautions have to be taken.

3.6. Discharge 6 in Fig. 1

Generally, a chemical cleaning of the membranes is performed with two types of

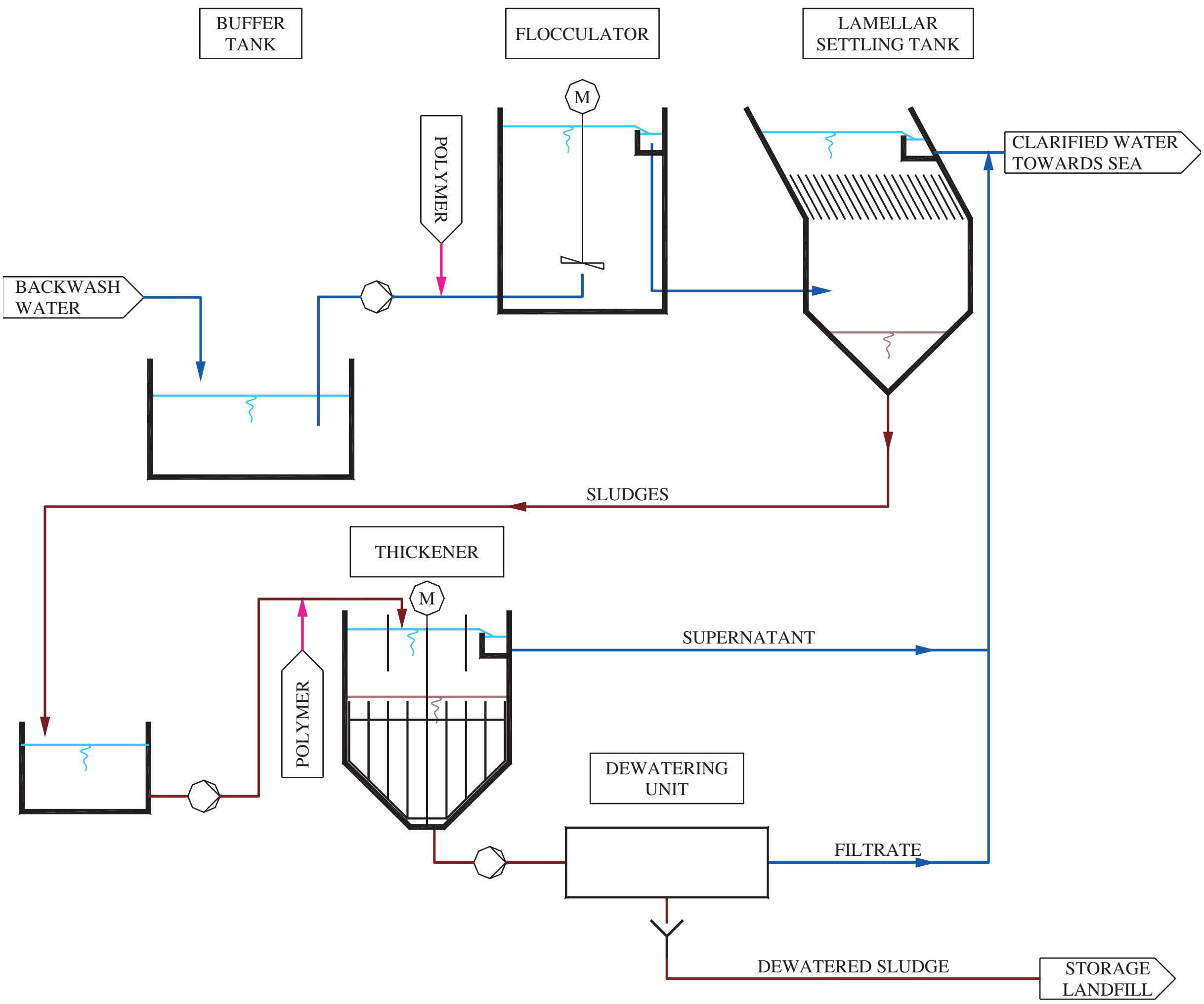

Fig. 2. Schematic diagram of filter backwash water treatment process.

solutions, first with an acid solution and then with an alkaline solution.

Therefore, it is advisable to discharge both of them in a stirred buffer tank in order to obtain auto-neutralization and then convey the mixture at a slow flow rate into the concentrate drain, to strongly dilute it, as indicated in Fig. 3.

4. Design for effluents discharge into sea

The main characteristic of effluents is their high salinity. To avoid an increase in the salinity of the sea water in the area surrounding the discharge point, it is necessary to dilute the effluent as quickly as possible.

To this end, the discharge should be made:

- in an area swept by stream and swell, thereby avoiding a discharge into areas more or less closed and calm (lagoons, for example);
- in a certain depth, generally eight or ten meters under the water surface at low tide;
- by a sea outfall with multiple port diffusers placed along 50–100 m at the end of

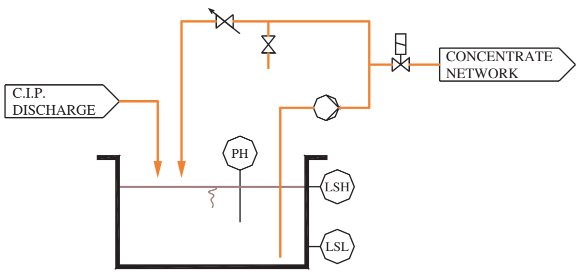

Fig. 3. Schematic diagram of the CIP effluent auto-neutralization.

the outfall, in order to spread the discharges over a large area;

- by directing the jets toward the surface at an angle of approximately 45° with respect to the sea bottom, in order to avoid:
- alteration of the sea bottom structure;
- stagnation of the effluent in the vicinity of the sea bottom, since its density is greater than that of seawater.
- by adopting a jet velocity which will be not less than 3.5 m/s.

The jet angle and velocity have an effect on the shape of the plume thus created. The greater the surface of the fall, the smaller the flow velocity will be at the sea bottom and the greater the dilution (Fig. 4).

The ports can be equipped with a check valve made of reinforced elastomer (Fig. 5).

These valves operate easily and reliably. They enable to isolate the outfall if the discharge stops. In addition, the pressure required to open them can be selected in order to homogenize the distribution of the flow on all the diffusers. Thus, the upstream valves, which are the most advantaged, will require a higher differential pressure than those located downstream.

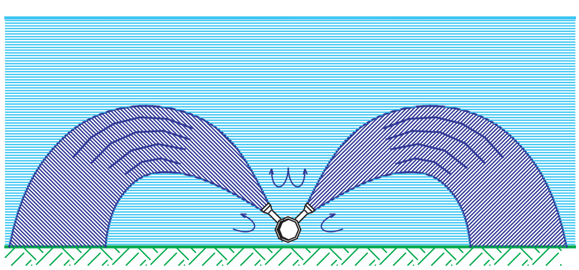

Fig. 4. Outfall cross section showing two inclined diffusers.

Other solutions can be considered to reduce the impact of the effluent, such as the dilution with other discharges:

- industrial discharge: if the desalination plant is located in the vicinity of an industrial complex, which uses large quantities of water for cooling requirements, such as power stations (case of hybrid "electric energy/water production" projects), it is interesting to discharge the effluents of the desalination plant into the evacuation channel of the cooling water which salinity is very close to the sea water's one and which flow rate is very high.
- urban wastewater discharge: if the desalination plant is intended to supply a nearby community in drinking water, the effluent discharged by the plant can be mixed with the treated water produced by sewage plant of the community, the latter having a very low salinity (approximately 500 mg/l). Thus, if the desalination plant is dedicated to this community alone and the discharge of this latter represents, due to various losses, a volume corresponding to 70% of the supply, the hydraulic balance in Fig. 6 shows an appreciable reduction of the global discharge with regard to that of the desalination plant effluent (–40% for the example, Fig. 6).

5. Recommendations for the desalination plant — location and design

5.1. Desalination plant location

The criteria for the plant location can be contradictory between those dedicated to the

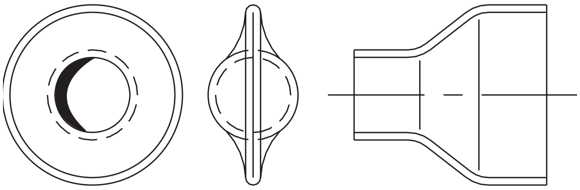

Fig. 5. Check valve for diffuser.

sea intake for supplying the plant and those dedicated to discharge system.

In the first case, the goal will be to find a site location far from any discharge and close to an area where the sea is smooth.

In the second case, the goal will be to find a site location with the possibility of diluting the plant discharge reject with other waste having a lower salinity, and close to an area affected by stream and swell.

The shore and the sea bottom profiles are also important. If the site is high above the sea level, the outfall will be gravitary. If this is not the case, a pumping unit will be necessary, resulting in electrical energy expenses increase. The sea bottom profile is also of importance, because to limit the outfall length, the depth required for a well diluted discharge must be quickly found (see section 4).

We are not going to discuss here the optimization of the investments needed to build the water intake and the outfall (considering, for example, the sea bottom structure: sandy or rocky).

5.2. Desalination plant design

Depending on the vulnerability of the discharge area relating to any increase in salinity, the designer may be obliged to limit the recovery, especially if the conditions required for a good dilution of the discharge cannot be obtained. Therefore, a compromise will be found between economical considerations and those involving the protection of the marine environment, because the higher the recovery, the lower the volume of sea water to be pumped will be, involving operation and

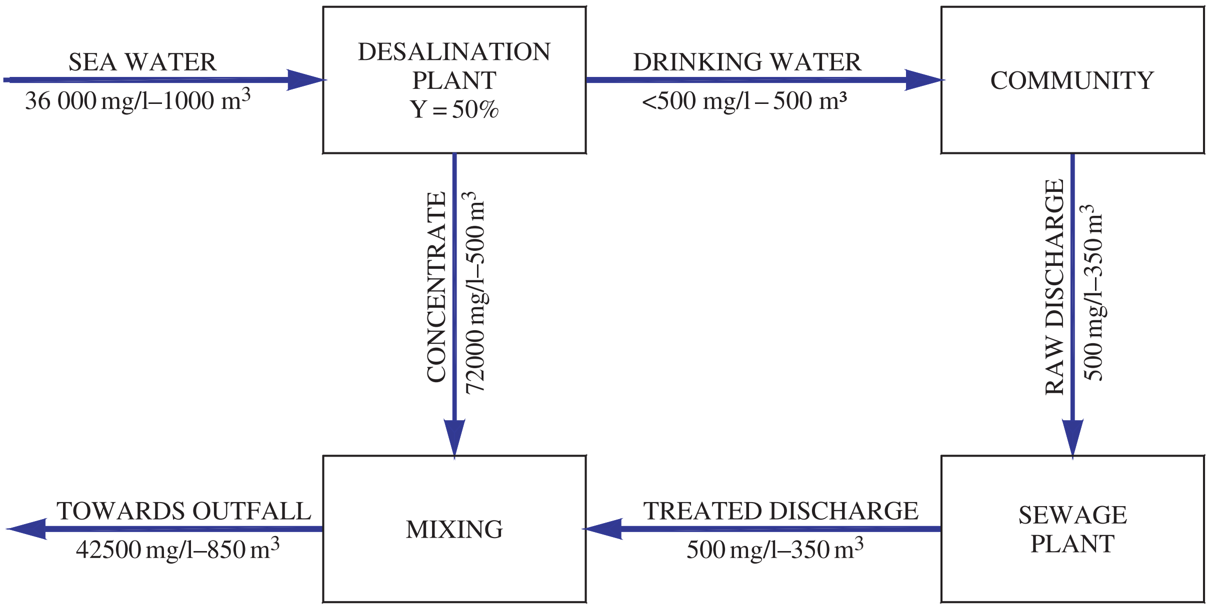

Fig. 6. Concentrate mixing with treated discharge from community—quality and hydraulic balance.

investment costs decrease. In order to maintain a high recovery while attempting to reduce the effluent's salinity, the most cost-effective solution will consist in increasing the pumped sea water flow rate so that a part of it can be devoted to diluting the concentrate.

The physical pretreatments must be correctly designed and sized:

- to avoid too frequent washings, which increase the discharge volume;
- to produce a water of very good quality to reduce the frequency of the chemical cleaning of the membranes and therefore limit the disposal of very concentrated solutions including miscellaneous pollutants.

To reach these objectives, the granular media filters should allow an in-depth filtration (use of dual media filters, anthracite and sand, for example) and have a low filtration rate, two characteristics affecting the duration of the cycles between two washings.

But one may be obliged to select higher-performance filtration techniques than those indicated above, calling on membrane technologies (microfiltration at 0.1 µm, ultrafiltration at 0.01 µm) which allow to obtain pretreated water with a low fouling index value close to 1, a value which tends to strongly reduce the number of chemical cleanings needed for the RO membranes.

The designer will also strive to minimize to the utmost the use of chemical products for pre-treatments. Thus, chlorination may be advantageously replaced by ultraviolet radiation. In this case, no chemical products will be used to oxidize bacteria, algae and miscellaneous microorganisms (plankton, etc.), or to eliminate the chlorine residual in order to protect the membranes.

5.3. Other aspects involving the plant design

With respect to the various effluents of desalination plants other than concentrate, the designer should allow for their collection in a buffer tank to avoid hydraulic shocks at the end of outfall, because their flow rate is highly variable.

The diagram in Fig. 7 proposes a solution allowing the elimination of flow peaks and the discharge of effluent with an almost constant salinity, thereby limiting the impact on the marine environment.

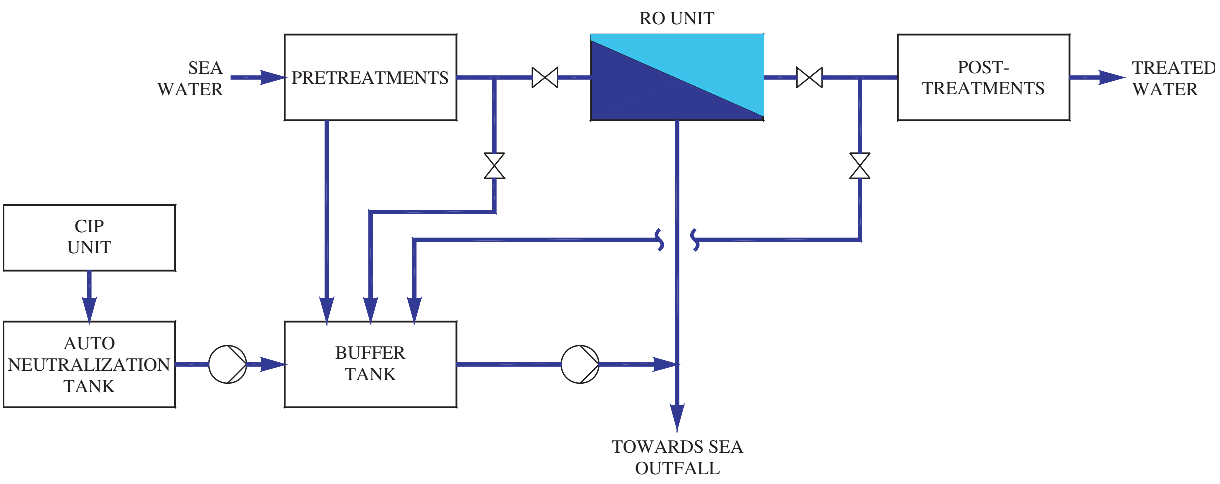

Fig. 7. Hydraulic diagram for homogenization (flow rates and characteristics) of the SWRO plant discharge.

6. Methods allowing a reduction in the volume of effluents

For economical reasons, at both the investment and operation cost levels, it is interesting to increase the recovery, which reduces the concentrate volume. Since the discharged quantity of salts remains constant, the discharge will have then a higher salinity. It will be advisable to dilute the discharge more effectively than for that obtained from a desalination plant sized with a lower recovery, for example by increasing the spreading area in the sea.

For extremely sensitive areas, we may also be obliged to limit the concentrate volume in order to:

- reduce the cost of the transport toward a less sensitive area;
- limit investments if specific treatment of concentrate is foreseen, by adding an evaporation system for example.

We had to wait for the arrival on the market of RO membranes operating at very high pressure (90 bars) to consider an increase of the recovery, from approximately 40 to 60%, corresponding to a reduction of the concentrate volume by about 1/3. Fig. 8 illustrates a RO unit using in the first stage conventional membranes, which concentrate is treated in a second stage fitted with high pressure membranes due to the increase of the osmotic pressure of the final concentrate.

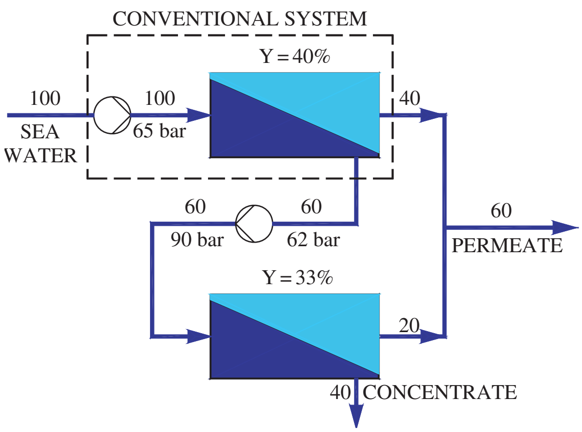

Fig. 8. Flow diagram of brine conversion two stage SWRO plant.

The recovery is therefore limited by the mechanical resistance of the membranes. If we want to concentrate the discharge even more, it will be necessary then to turn to evaporation, which may be either natural or thermical.

In the first case, the effluent is admitted in shallow basins offering therefore large surfaces.

In the second case, the effluent is admitted in a thermal evaporator applying, for example, mechanical vapor compression (Fig. 9).

Both processes result in concentrating the effluent until a saturated brine is obtained, with a concentration of 260 g/l about.

Natural evaporation requires very large surfaces, but offers the advantage of requiring only a limited number of mechanical equipments. The evaporation rate depends on local climatic conditions: sun and wind conditions, relative humidity.

Thermal evaporation leads to high investment costs and high electric consumption, but offers the advantage of producing a condensate which will increase the fresh water production.

These two techniques can only be foreseen for very special cases and, in any case, only for low flow rates.

7. Conclusion

In order that a desalination plant can best respond to the ecological requirements of a marine site, the plant designer has to be assisted by many competences to have the best possible knowledge about the environment, i.e.:

- sea bottoms (relief, structure, . . .);
- bathymetry (tides, swell, etc.) and streams;
- climatology;

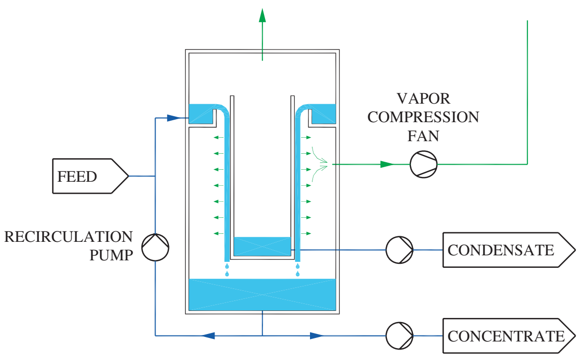

Fig. 9. Operation principle of a MVC evaporator.

- surrounding human and industrial activities;
- ecological constraints and requirements.

These data will allow to confirm the choice of the plant location, to orientate the design of the SWRO plant as so the sea works (intake, outfall), towards solutions enabling a maximal reduction of disposal impact on the environment, while respecting economical requirements in terms of investment and operation costs.

This search for a high environmental quality plant also concerns existing desalination plants, for which the following are also to be sought:

- improvement of pretreatments (discharge reduction, discharge treatment, improvement of feed water quality for the RO units, . . .)
- utilization of the concentrate by setting a second stage using high-pressure membranes, which, in addition to reduce the concentrate volume, allow the increase of fresh water production;
- reliability of the electric energy supply in order to limit untimely start-ups and shutdowns leading to additional discharges.

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