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Design of marine outfalls for reducing environmental impact of brine

Eloy Pita*, Pablo Pita, Mario Sánchez-Barriga, Lucas Martín, Javier Olalde

Ingeniería Creativa Pita S.L. (INCREA), Calle Buganvilla 6, Portal 1, 1ºA, 28036 Madrid, Spain,
emails: epita@increa.eu (E. Pita), pitapablo@increa.eu (P. Pita), msanchezb@increa.eu (M. Sánchez-Barriga), lmartin@increa.eu (L. Martín), jolalde@increa.eu (J. Olalde)

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ABSTRACT

Marine installations for desalination plants have two aims: the intake gets water from the sea to feed the desalination plant and the outfall discharges brine back into the sea. A proper design of these works should accomplish its functional aims with enough safety, low affection to the environment and at the lowest cost. The Spanish Consulting Company INCREA has been designing marine installations for desalination plants for the last 18 y around the world. Its projects have been developed in all the continents and for any size of desalination plant: water intakes developed by INCREA range from 300 mm of diameter to 3,000 mm. The aim of this presentation is to show the way INCREA solves the issue of reducing impact of brine in the environment and avoiding recirculation of brine into the intake. It will also show different solutions for solving specific problems. The correct use of software tools for studying the behaviour of the brine plume is essential. INCREA mainly uses Brihne and Mohid for this anaysis. We also present the lessons we learned thanks to our experience in this field in several desalination Projects designed by INCREA (all of them constructed or under construction): Skikda, Beni-Saf, Cap Djinet and Mostaganem in Algeria; Valdelentisco, Aguilas, Mutxamel, Santa Eulalia, Campo Dalías and Escombreras in Spain; Sorek in Israel; Qingdao in China; Mantoverde and Spence Growth Option in Chile; Nungua in Ghana; Al Ghubrah in Oman; Djerba and Zarat in Tunisia; El Alamein, El Arish, Negeelah, Taba, Sharm El Sheikh and East Matrouh in Egypt; Jazan Economic City, Red Sea and Shuqaiq-3 and Shuqaiq-1 in Saudi Arabia; Lima Sur in Peru. Many pictures of these plants are shown, for an easy understanding of the works.

Keywords: Outfall; Environment; Dilution; Desalination; Sealines; Intake; Brine

1. Introduction

Most desalination plants take water from the sea and discharge brine back into the same sea. Besides the importance of the intake system, the outfall is a keystone in the correct operation of these plants.

The aim of the outfall is to discharge brine (seawater with a high concentration of salt) into the sea, through the last section of it. This last stretch is called the diffuser and its geometry should be designed with the aim of getting the larger possible dilution without increasing hydraulic headloss in the system too much.

From an environmental point of view, the design of the outfall (and its diffuser) should be done according to the following premises:

High initial dilution, so as the surrounding area is not affected by the discharge.

High far-field dilution, avoiding recirculation in the intake and not affecting sensitive areas.

Marine installations are a very important part of the CAPEX of a desalination plant. Choosing a experimented

* Corresponding author.

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designer is a key for reducing construction costs and operational risks.

INCREA has vast experience in the design of marine pipelines all around the world for any purpose (cooling circuits, sewage, fish farms, etc.), but, specially, for desalination plants. The purpose of this paper is to describe the design process and to show lessons learnt thanks to our experience in the design of various projects (all of them constructed) over all these years.

2. Dilution of brine

2.1. Near field dilution

2.1.1. Process of dilution

Brine has a salinity of around double of that of seawater, which means it is denser. When this effluent is discharged into the sea, it sinks (negative buoyancy) due to the higher density and forms a dense and hypersaline layer that moves along the seabed following the local bathymetry.

This is why the exit angle of the ports is always looking upwards: a parabolic path is followed by the brine before it touches (diluted) the seabed.

The highest dilution levels are achieved during the initial dilution process, when the turbulent brine is mixed with the receiving body (red colour in Fig. 1). The initial dilution process mainly depends on the discharge velocity and its angle, which changes with the number of outlet ports, diameter and direction of the outlet ports, etc., meaning this is the process where the designer can work to improve the discharge dilution.

When the discharge collides against the seabed, a hydraulic jump forms and, after this, the dense layer moves as a density current. This dense and hypersaline layer can be harmful to benthic organisms in the affected area which requires a discharge system that is capable of adequately diluting the brine to ensure there is no damage to the marine environment.

There are some patented designs of outfalls that increase initial dilution.

2.1.2. Software tools

INCREA recommends using brIHne model for near field. These tools are a set of numerical models developed by the Environmental Hydraulics Institute of Cantabria (IH Cantabria) to simulate the behaviour of brine discharges from the desalination plants. These tools have arisen as an extension of the research carried out in the MEDVSA project (www.medvsa.es), in which a methodology to design brine discharges was developed for the Ministry of the Environment and Rural and Marine Affairs of Spain. Within the scope of the project, a critical assessment and validation of the most used commercial models to simulate brine discharges (Cormix, Visual Plumes and Visjet) was carried out, Palomar et al. [1,2]. Conclusions revealed significant shortcomings and a poor agreement with experimental data when simulating this type of disposals.

An important advantage of "brIHne" discharges is the re-calibration with experimental data obtained by tests carried out in IH Cantabria. For this reason, the re-calibrated "brIHne" tools present a good agreement with experimental data and therefore they are feasible models to simulate actual desalination plant discharges.

2.1.3. Environmental criteria

There are different environmental criteria in the world about the maximum admissible salinity after the mixing zone, to avoid damaging sensitive areas.

There are different environmental criteria (depending on the Country) that shall be verified when designing the diffuser. The more commonly criteria used around the world are:

- 1–2 g/L over sea salinity.
- 2%–5% over sea salinity.

The final criteria will depend not only on the country where the desalination plant is located, but also on the area in which it is constructed: sensitive environmental zone, industrial zone, etc.

2.1.4. Interface between near and far field

After initial dilution, the process of increasing the dilution takes place with lower efficiency, as the brine runs on the seabed with less contact with the surrounding water. In that moment, far field dilution starts, and it is more related to ambient conditions as bathymetry, currents, etc, where the designer has less chances to act.

Software should model properly this interface between near and far field. Once the initial dilution is run and the results are appropriate, (the diffuser has been correctly designed), it is crucial to implement its results in the far field model.

The results of near field model play a very important role in global dilution. Therefore, different techniques of coupling in function of the flow and the hydrodynamics of the site should be considered in order to define the most appropriate one and, in that way, to assess correctly the interface between near and far field.

2.1.5. Far field dilution

2.1.5.1. Process of dilution

As explained above, this analysis should be done where ambient conditions are more relevant than effluent discharge velocity, as near field models have a lack of precision (Fig. 2).

This dilution in the far field is mostly conditioned by the local hydrodynamics (currents at the seabed) and bathymetry, with much lower dilutions, as said before. The hydrodynamics in the area are mainly conditioned by tides.

The purpose of the far field dilution study is double:

- to check that recirculation of brine is avoided in the intake (Fig. 3).
- to measure salinity in sensitive points, far from the discharge (for instance, verifying that the environmental impact is admissible).

With this study, the location of the intake tower and the diffuser can be optimised.

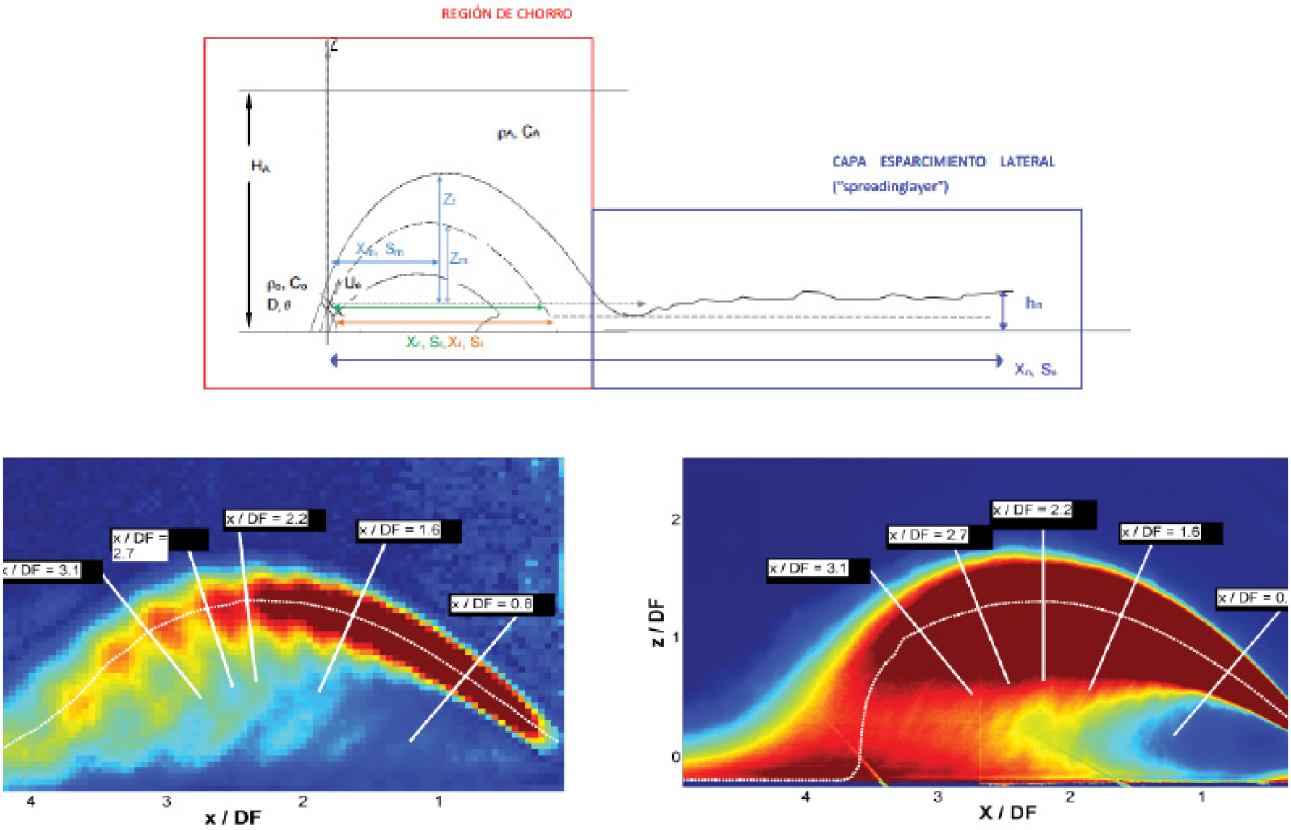

Fig. 1. Simulation of the discharge (including jet and spreading layer) using BrIHne-Jet-Spreading model.

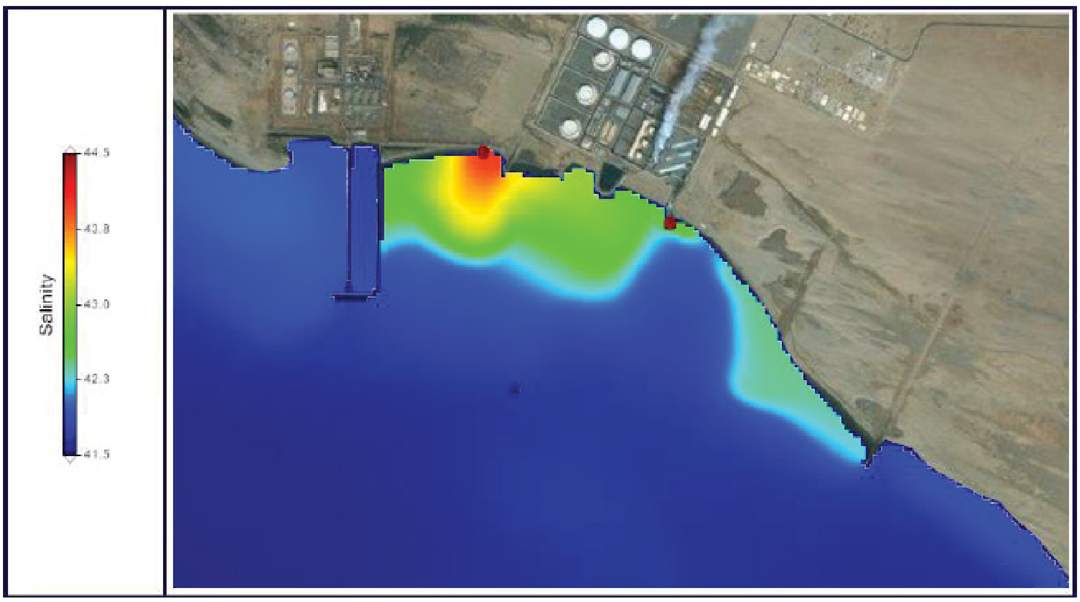

Fig. 2. Example of a discharge in Shuqaiq-3 desalination plant (Saudi Arabia – 2021).

2.1.5.2. Recirculation limits

The definition of the recirculation criterion is not as defined in the legislation as the environmental criteria. This is an operating criterion to avoid inflow brine discharged by the diffuser, optimizing the desalination process.

Next limits are commonly used:

- Average recirculation value: less than 0.2 psu.
- Maximum recirculation value: less than 0.3 psu.

2.1.5.3. Software tools

Dispersion along the far field is studied by INCREA with MOHID Model.

MOHID is the short name for Modelo Hidrodinámico, which means Hydrodynamic Model in Portuguese. MOHID Water Modelling System is a modular finite volumes water modelling system.

It is an integrated modelling tool able to simulate physical and biogeochemical processes in the water column as well as in the sediments and is also able to simulate the coupling between these two domains and the latter with the atmosphere.

The MOHID system includes a baroclinic hydrodynamic module for the water column and a 3D for the sediments and the correspondent eulerian transport and lagrangian transport modules. The program also includes specific modules for processes involving non-conservative properties (e.g., turbulence module, water quality, etc.). In addition. One of the most important features of MOHID is the possibility to run nested models. This feature enables the user to study local areas.

2.1.5.4. Relative location of the intake and the diffuser

In general terms, it is desiderable to place the intake structures at deeper location than the outfall diffuser (Fig. 4).

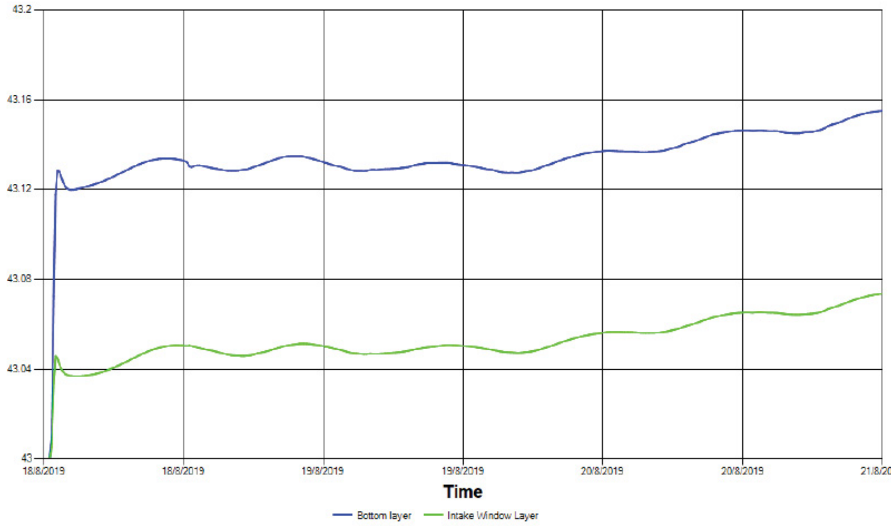

Fig. 3. Example of the evolution of the salinity at a certain point in Shuqaiq-3 desalination plant (Saudi Arabia – 2021).

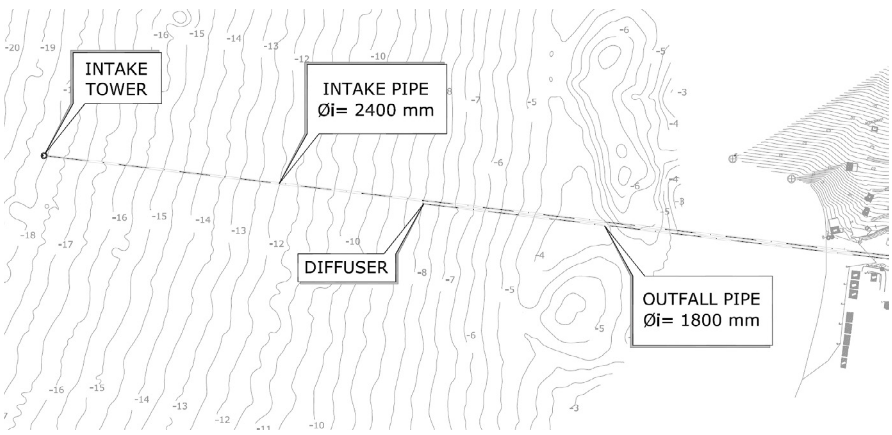

Fig. 4. Layout of Beni Saf desalination plant (Algeria – 2007) where the intake tower is deeper than the diffuser stretch.

If the project is located in an area where the bathymetry has a very small slope (shallow waters), and where water has low turbidity or the action of waves is limited, then the diffuser could be better be located at an area deeper than the intake structure.

Placing the intake system further from the coast than the outfall system has the following pros and cons:

- *Advantages*
  - Better water quality is taken from the sea.
  - Less exposure of the intake structure to wave actions. This means that less weight is needed for getting its stability.
  - More distance to the sea surface (avoiding marine microorganisms growth, as a result of less exposure to sunlight).
  - More distance to the seabed can be reached (avoiding sediment ingress into the tower).
  - Intake structure geometry: as there is more space, lower water velocity at the tower windows can be obtained.

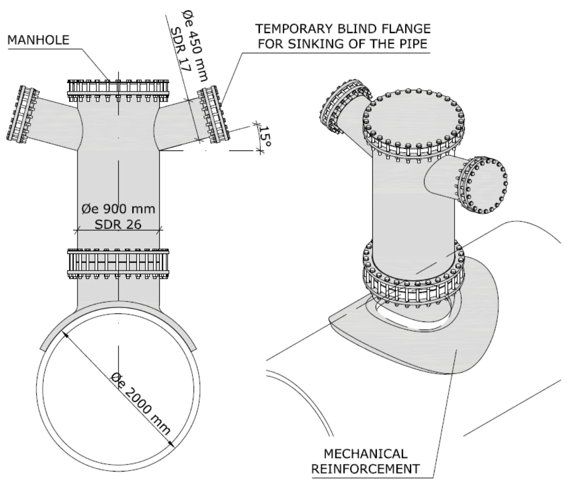

Fig. 5. Section and 3D view of riser with two outlet ports used in a desalination plant in Egypt. The angle of the ports with the horizontal plane is smaller than usual, because its location is very shallow.

- *Disadvantages*
  - The cost of construction of pipes will rise: as the length of the intake pipelines is longer and keeping into consideration their higher diameters, the total cost of the project will increase.
  - The action of the gravity could lead the brine towards the intake towers area and may cause higher recirculations.

2.1.5.5. Hydraulic behaviour inside the pipes

Reducing headloss in the outfall allows to reduce the need of pumping. If brine piezometric level at the plant is high, reducing headloss in the diffuser allows to reduce the diameter of the main pipe of the outfall and, consequently, its construction cost.

2.1.5.6. Use of large riser diameters

The size of the risers of the diffuser does not affect the initial dilution, as it is only function of the velocity of the effluent when leaving the port, and this is only related to the outlet port size. A greater diameter of the riser will reduce head losses in them (Fig. 5).

2.1.5.7. Design of special pieces

Using special pieces, with internal hydrodinamic geometry, in the diffuser section, will make the flow of brine easier and reduce the head losses in the system. Sometimes, their particular shapes make complicated to use HDPE for their manufacture. Other materials, such as GRP, can be used to assemble these pieces (Fig. 6).

2.1.5.8. Uniform flow

The diffuser stretch must guarantee flow is as uniform as possible through the outfall ports along the full length of the diffuser. In case all the risers had the same geometry, the discharge of the brine would get smaller as it goes forward. A lower brine flow and the subsequent lower speed of the discharge, will lead to worse performance of the system (worse dilution) in that specific port.

Fig. 6. Drawing and picture of diffuser section with a GRP special piece installed in Valdelentisco desalination plant (Spain – 2007).

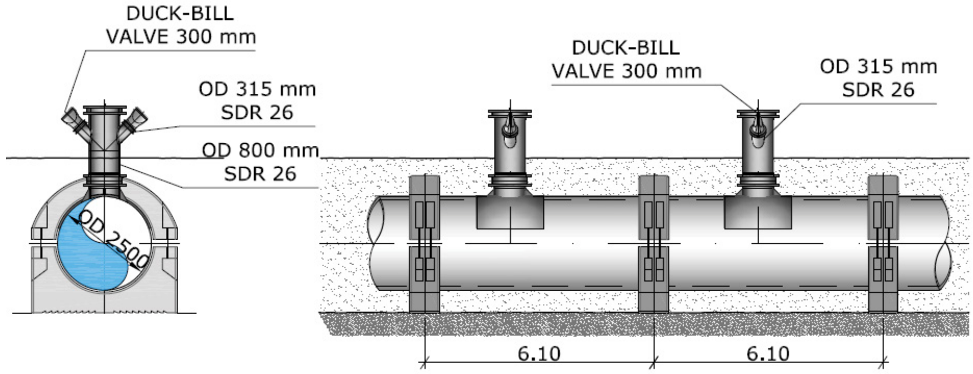

Fig. 7. Duck-bill valve for a project in Asia.

Fig. 8. Valdelentisco desalination plant launching of the pipes. The lower part of the riser can be seen in the right photo.

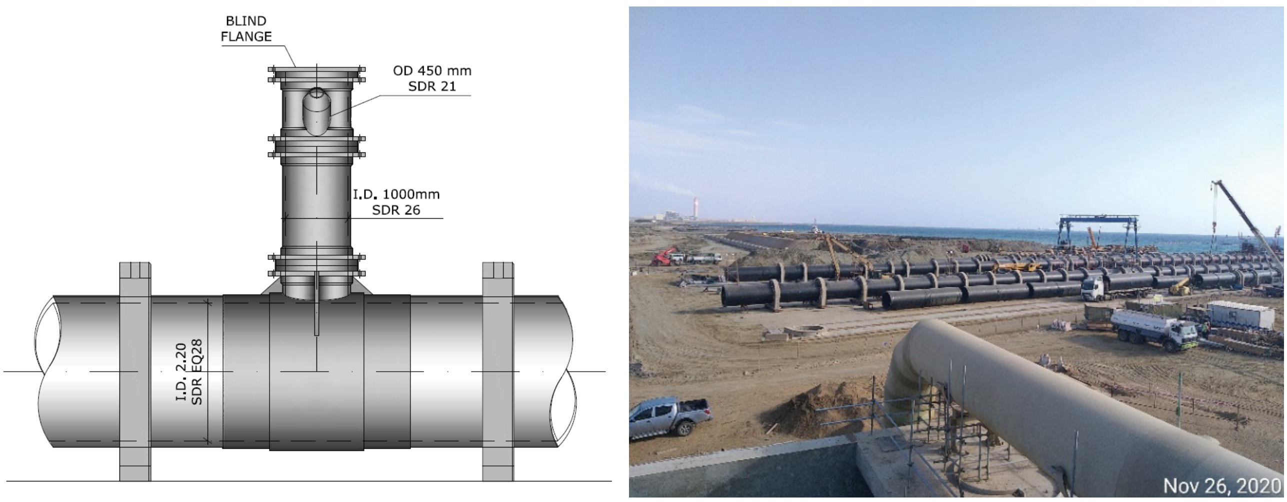

Fig. 9. Shuqaiq-3 riser and outlet definitions and image of the pipes during construction.

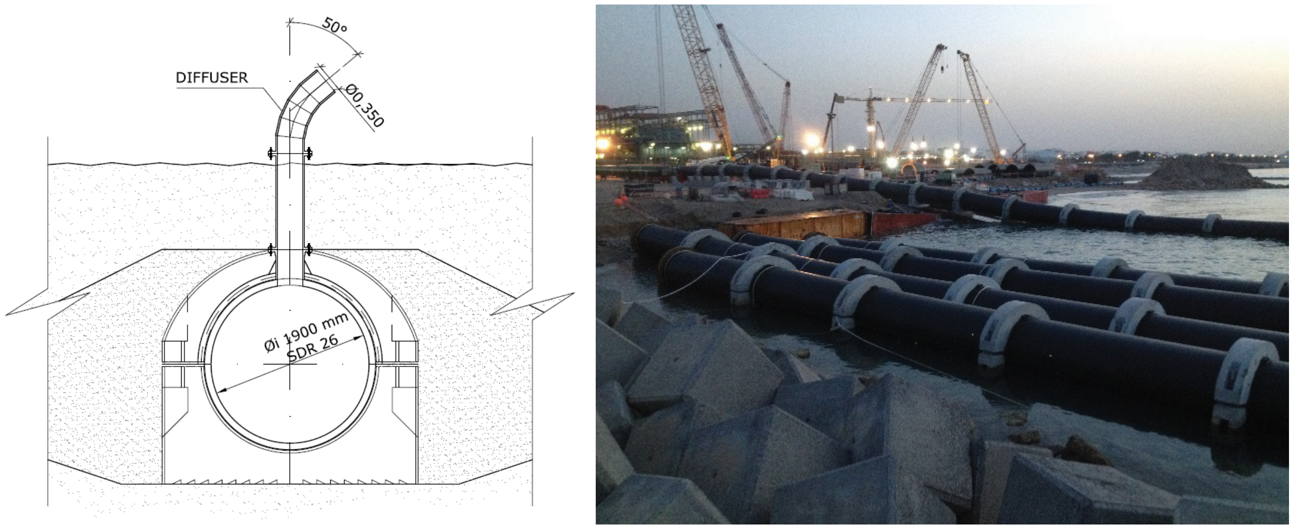

Fig. 10. Al Ghubrah desalination plant diffuser section and launching of the pipes.

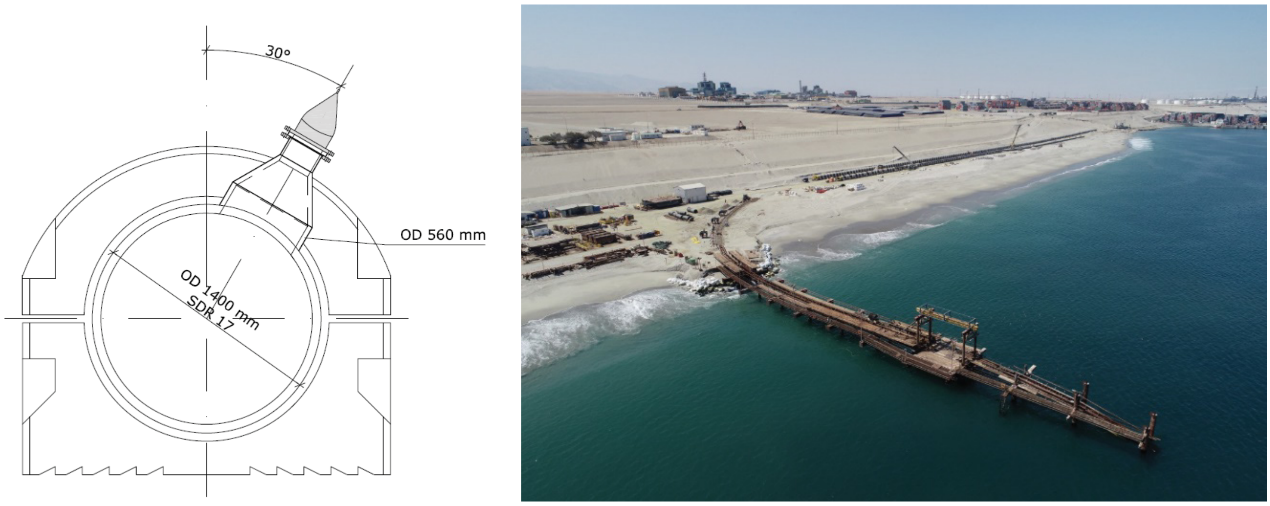

Fig. 11. Diffuser section and launching rampe in Spence Growth Option desalination plant (Chile).

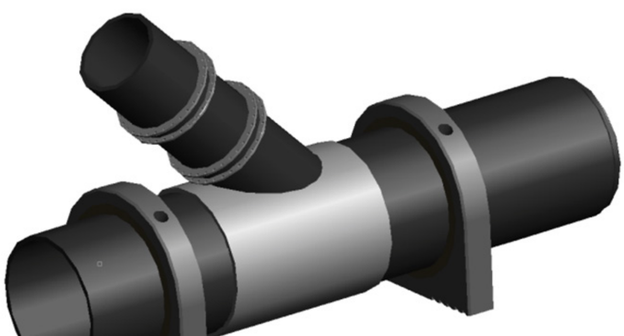

Fig. 12. Diffuser installed in Skikda desalination plant (Algeria).

To ensure this uniform flow, it is appropriate to vary the diameter of the risers of the diffuser stretch (from lower to higher diameters).

2.1.5.9. Duckbill valves use

A duckbill valve (Fig. 7) opens and closes its mouth when flow rises and goes down, respectively.

During normal operation, there is no incentive in installing these valves as no salt intrusion can happen.

The design of the outfall system studies the typical operational situation, for a certain flow obtaining a good dilution. The larger velocity flow has, the bigger dilution is obtained, but local headloss increase.

As the hydraulic head loss depends on the square of the exit velocity, an increase in flow can lead to a sharp increase in headloss. The main benefit of these valves is to limit the head losses in case the flow varies. During the normal situation, the valve will remain almost closed (leading to high velocities and, thus, high dilution), but in case the discharge is greater, the opening degree increases. This allows the system to have the head losses limited, as its increment (in case the flow varies) is low compared to the situation without valve.

However, it is very important to be cautious with the actions of a tsunami or high tides, in case these valves are installed. If the pipe empties when the sea water recedes, then, when the water goes forward again, the overpressure can cause the buckling of the valves.

2.1.5.10. Experience from desalination plants outfalls

During all these years, INCREA has successfully developed many projects all around the world, solved different issues and learnt about the construction, transport, installation and behaviour of the marine works. Some examples (where diffusers are shown), are the following:

Valdelentisco desalination plant (Spain – 2007) (Fig. 8)

- Intake pipeline: 1 × PE ID 1.80 m – L = 1,450 m
- Outfall pipeline: 1 × PE ID 1.50 m – L = 1,260 m

Shuqaiq-3 desalination plant (Saudi Arabia – 2021) (Fig. 9)

- Intake pipeline: 3 × Structured PE100 ID 2.20 m – L = 3 × 1,700 m
- Outfall pipeline: 1 × Structured PE100 ID 2.20 m – L = 2,300 m

Al Ghubrah desalination plant (Oman – 2013) (Fig. 10)

- Intake pipeline: 2 × PE100 ID 1.70 m – L = 2 × 1,600 m
- Outfall pipeline: 1 × PE100 ID 1.90 m – L = 1,125 m

Spence Growth desalination plant (Chile – 2021) (Fig. 11)

- Intake pipeline: 1 × PE100 OD 1.60 m SDR 26 – L = 655 m
- Outfall pipeline: 1 × PE100 OD 1.40 m, SDR 17 – L = 515 m

Skida desalination plant (Algeria – 2006) (Fig. 12)

- Intake pipeline: 1 × PE ID 1.80 m – L = 1,170 m
- Outfall pipeline: 1 × PE ID 1.50 m – L = 675 m

3. Conclusions

A proper design of a brine outfall is essential for avoiding environmental impact and recirculation of brine. The sea is a harsh environment and expert designers are needed for reducing construction and operation costs and operational risks.

Acknowledgement

We want to thank all our clients, that have trusted in our capabilites for more than 20 y, all over the world.

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