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Review Article

MODELLING AND DESIGN OF BRINE OUTFALL DISCHARGES: CASE OF A DESALINATION PLANT IN MEDITERRANEAN

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ABSTRACT

In the various actions of desalination plant Project, the one to which it attaches great importance from an environmental point of view, is the waste discharge of brine poured in marine and coastal environments, since it is about of a continuous waste of significant flow with important salinity. This salinity difference conditions the environmental salinity behaviour. To determine this behaviour, the effluent dispersal poured by underwater outfall has again been studied. In order to reach this aim, dilution characteristics of the future outfall have been evaluated and concentrations of rejected brine under worst case conditions have been estimated. Also, it has been carried out the analysis of various design alternatives which allow improving efficiency of the waste management in order to increase dilution of brine. With of view to meeting this study, the CORMIX model has been of a significant contribution and Delft-3D-Flow as an audit model.

INTRODUCTION

Algeria has a 1200 km coastline on the southern rim of the Mediterranean, which offers great potential for the desalination of seawater to supply much needed drinking water. The desalination plant of Fouka, located in West-Algiers area, Mediterranean coast (Fig. 1), capacity is of 120.000 m^3/day; using the reverse osmosis process. The project effectively started on July 2011, supplying three surrounding municipalities and comprised of six trains of SWRO each one is able to produce continuously 20.000 m^3/day not equipped with reserve units. Each train is fitted with a high-pressure pump, these pumps are designed to be able supplying the necessary pressure required by membranes at 15°C and for salinity of 38.000 mg/l. The equipments characteristics are based on specific types of membranes, of energy recovery systems, a defined number of pumps and operating with independent temperature energy use.

The building and exploitation of the desalination plant will be subject to an environmental impact assessment on local environment. In effect, brine is discharged in coastal waters, generating a potential harm on marine environment (Altayaran and Madany, 1992; Del-Bene, *et al*., 1994; Morton, *et al*., 1996; Ahmed, *et al*., 2000; Jaime, *et al*., 2005; Miri & Chouikhi, 2005; Alameddine and El-Fadel, 2007; Lattemann and Höpner, 2008; David, *et al*., 2010; Mezher, *et al*., 2011; Nadeem and Raouf, 2014; José, 2014; Maedeh, *et al*., 2015; Maedeh, *et al*., 2015), particularly on benthic and stenohalin communities Oceanica posidonia and seagrasses Cymodocea nodosa (Gacia, *et al*., 2007; Sánchez-Lizaso, *et al*., 2008; Palomar and Losada, 2010).

The high salinity concentration could also lead to an increase of water turbidity, which is more likely to reduce the penetration of light, effect which could disturb photosynthetic processes (Miri and Chouikhi,

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Fig. 1 Localization of the desalination plant. Source: Personal work.

2005). For this purpose, it should be chosen the best location for installation. The dimensioning of outfall, having a direct effect on brine dilution, is also a fundamental part in environmental protection.

According to the preliminary work carried out by safege (French Limited Company for the Study of Management and Business) for desalination plant of Zeralda, and according to simulation results, the discharge of brine generates the increase of salinity on the upper bottom at 1 g/l within 50 m from the discharging area, comprised between 0,4 and 0,6 g/l (according to the current velocity) in far-field. In the present case of this study, this aim would be reached by evaluating dilution characteristics of the future outfall and brine concentrations poured in the most unfavorable conditions should be estimated. In addition, analysis of different design alternatives has been made (effect of the aperture height, diameter of piping, orientation of diffusers, depth of waste point, etc...).

This paper explains the technical elements of the plant, the design of the approach diffuser system, conceptualisation of the digital models regimes for effluents at short and far-field of the mixing zone, and design of the selected diffuser with a particular emphasis on modelling of mixing process in near-field. For this purpose, the CORMIX model is used and approved by USEPA (U.S. Environmental Protection Agency) for simulation of mixing processes of discharges into the sea. This tool is particularly adapted to near-field mixing and useful in reduction products effects on the marine environment by continuous and punctual discharges (Akar and Jirk, 1991; Girka, *et al.*, 1996; Bleninger and Jirka, 2006; Bleninger and Jurka, 2010). The detailed comparison with available field and laboratory data showed that predictions of CORMIX system on plume dilutions and concentrations (with associated plume geometries) are reliable in most cases (Pun and Davidson, 1999; Kang, *et al.*, 2000; Roberts, *et al.*, 2010; Roberts and Tian, 2004; Azimi, *et al.*, 2005; Kikkert, *et al.*, 2007; Sanchez-Lizaso, *et al.*, 2008). Delft-3D-FLOW is a model of hydrodynamic process and of transportation in three dimensions, which simulates flow and transport of unsteady phenomena resulting from meteorological and tidal forcing. The Delft-3D-FLOW is a far-field model (Bleninger, 2006; Bleninger and Jurka, 2010). The alternative approach at combined use of near-field and far-field models has been explored in various studies (Bleninger and Jirka, 2008; Bleninger and Jurka 2010; Morelissen, *et al.*, 2011; Botelho, *et al.*, 2011). The Delft-3D-FLOW model was mainly used to confirm the selected diffuser design from the near-field model.

TECHNOLOGICAL ASPECTS

Plant description

1. The desalination plant of Fouka has a nominal capacity of 120.000 m^3/day of drinking water. The main components of the plant are as follow:
2. An open seawater intake – water intake head;
3. Sea water pumping station;
4. Water pre-treatment of gravitational filtration and cartridges filters;
5. Desalination by reverse osmosis with energy recovery;
6. Remineralisation with addition of alkaline products;

Ancillary systems

1. Networks, controls, preparation systems and

dosing of chemical products, cleaning system of membranes, equipments and cleaning product;

2. A treated water reservoir with supply-water pump station and;
3. Buildings of services, booth.
4. From a treatment line point of view, this desalination plant is completely conventional as can been seen in (Fig. 2).

Seawater intake

Seawater intake is designed to supply sea water in quantity and quality to comply with design values of the desalination plant. Two water intakes are set at least 6 and less than 8 m to avoid particles collected from the sea floor, re-suspended by currents action and to avoid venting caused by strong swells (Fig. 3). The input velocity of water intake is limited to 0,1 m/s in order to avoid suction of debris and solid particles in suspension. The water intake is composed of two pipes in PEHD, with a length of 850 m and of DN1600. Each of both pipes carries the whole sea water required for production of 120.000 m^3/day. The pumping station of raw water is intended to bring up to a sufficient level to produce a gravity flow into the pre-treatment system. The pumping station based on 6 + 1R pumps type centrifugal horizontal and vertical, each one with capacity of 1974 m^3/h, (total 11.844 m^3/h >11 404 m^3/h to absorb the additional flow during maturation of sand filters). A static mixer on raw water pipe which ensures mixing of chemical products injected in this spot (sulfuric acid, ferric chloride, and polyelectrolyte).

Pre-processing

In order that the plant can safely and efficiently operate, water supplying osmosis sectors is pre-treated in order to possess some physical, chemical and biological characteristics. At the level of gravitational filtration, it is opted for installation

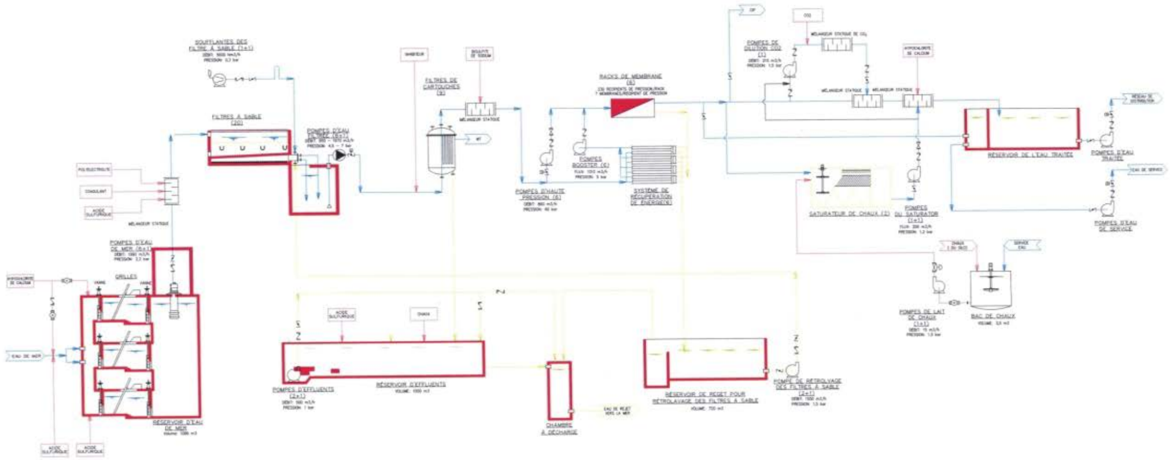

Fig. 2 General schematic of the process.

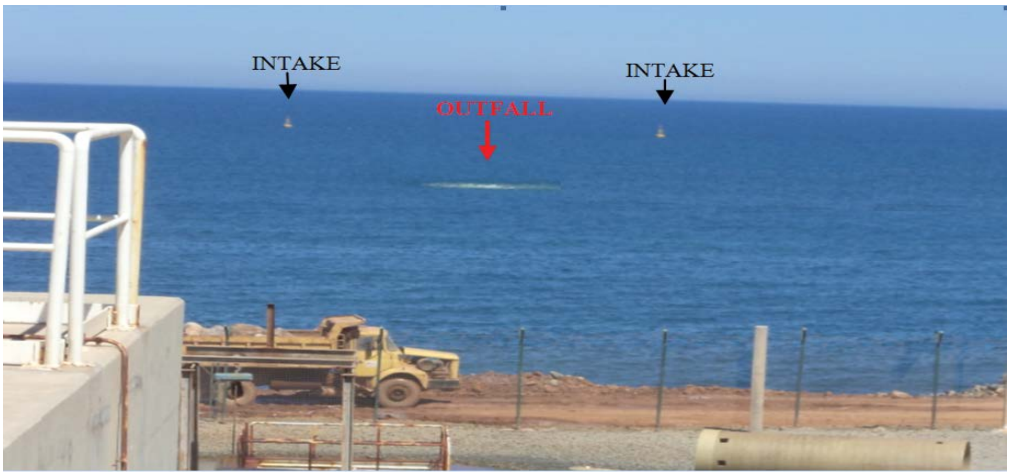

Fig. 3 Seawater intake and marine outfall systems. Source: (Personal photography, June 2017).

of bilayers filters. In bilayers filters, the upper layer is made of thick material and of low density (anthracite in the present case). In this initial layer that most of particles are retained. The lower layer contains thin and thicker material constituting a refining processing. Both of layers are classified by fluidization through densities and different natures of filter materials. For this first filtration step, it is used twenty open bilayers (18 units in service adding 2 in washing or in maturation), of 77.5 m^2 size each one. For filter washing, a brine reservoir of 750 m^3 is used. This reservoir has a sufficient capacity to realize filters washing, a filtered water reservoir of 950 m^3 volume to store filtered waters before their pumping towards cartridge filters. In order to filter small particles which escape from sand filters and thus protect membranes against particular matters, cartridge filters capable of filtering particles until 5 microns are placed upstream of osmosis units.

Configuration of the reverse osmosis system and recovering rates

The reverse osmosis station necessitates only one (1) passage in order to reach the required rate of dissolved solids. The recovery rate is estimated to 45%. Osmosis station is endowed of equipments as follows in Table 1.

Membranes of reverse osmosis

After treatment, water is pumped with high pressure pumps to reverse osmosis module. Six RO membranes are set to a passage. Osmosis membranes are connected to a common collector supplied by the six high pressure pumps made of stainless steel DUPLEX. Their characteristics are summarized in Table 2.

Remineralisation

The project of Fouka is equipped of a remineralisation system to correct hardness and alkalinity, in order to stabilize the nature relatively aggressive of desalinated water produced, providing a more satisfactory taste and meet the quality requirements as defined in standards. The remineralisation system

Table 1. Equipments of reverse osmosis station. In nominal conditions of functioning, the production is ensured by the six channels. Source: Fouka's desalination plant.

Parameters	Number
High pressure pump	Six (6)
Energy recovery device	Six (6)
Booster pumps	Six (6)
Reverse osmosis trains first passage	Six (6)
Cleaning system and flushing	One (1)

Table 2. Characteristics of reverse osmosis channels. (1)Production 120 000 m^3/d + 1% service water Source: Fouka's desalination plant.

Parameters	Values	Total
Number of racks operating	6	6
Number of racks in stand-by	0	0
Recovery (%)	45%	--
Production by membranes	842 m^3/h	121 200 m^3/d (1)
Feed water flow by membranes	1 870 m^3/h	269 333 m^3/d
discharge flow	1 029 m^3/h	148 133 m^3/d
Number of tubes by rack	233	1398
Life of the membranes	3,2 – 5 years	--

comprises a dosing system of CO_2 which will react with calcic (lime), CO_2 is produced on site from a CO_2 generation system (Fig. 4)

Pumping of treated water

The internal water transport network to the desalination plant includes a treated water pumping station to bring the water to the distribution network (external network) according to requirements as follows:

Totality of pumped flow is delivered by a pumping station with a single backflow collector;

A pumping line capable to transmit the totality of pumped flow of 120.000 m^3/day with capacity of 24 bars. The six pumps added with a reserve pump of pumping station will work at fixed flow and/ or varied in order to insure flow fluctuation and pressure (Fig. 5).

Effluents treatment

Process discharges include the following:

filters washing waters;

washing or flushing waters of reverse osmosis (distinct pipe of evacuation one of respite valve installed on supply collector of reverse osmosis units;

These waters and only these waters are forwarded to the effluents treatment reservoir (effluents neutralisation) and, from there to the outfall;

Once in the reservoir, surplus water is released through the overflow of the reservoir and directed to the outfall discharge room, outfall is composed with pipe of DN1400 in PEHD of length 500 m. Concentrate (reject) water discharge of reverse osmosis units is directed to reservoir of filters washing waters. The equipments drains are released on planks and/or drainage points. They will be directed to a single

Fig. 4 CO_2 produced on site. Source: (Personal photography, June 2017).

Fig. 5 Treated water pumping station. Source: (Personal photography, June 2017).

capture point and to effluents processing reservoir via a pump system, sumps and/or pipes. There is no drainage of retention tanks of chemical products except of CIP drainage waters which will be sent to the washing waters network.

Methodology and calculation

During exploitation, brine mixing, cooling water and washing effluents of filters and membranes will be rejected by discharge channel proposed. Brine has a concentration in TDS about 69.000 mg/l. The operational discharge flow is of 5638.33 m^3/h (1.56 m^3/s). Due to the high rate of evaporation and low freshwater inputs, salinity in western Mediterranean is about 38.000 ppm. The rejection of brine in the sea containing a concentration in TDS of 69.000 mg/l, the salinity located in the immediate neighborhood of the discharge canalization will increase; effect may take place locally on marine flora and fauna. For this purpose, the CORMIX model is used by analyzing effluent dispersion to be poured by the underwater outfall in various oceanographic conditions, wind and current, in order to determine the most unfavorable scenario. The used model is CORMIX to study the dispersion process of near-field in order to determine efficiently different parameters of waste dilution of Fouka's desalination plant. The CORMIX Code is recommended par EPA (Environmental Protection Agency, USA). The Cornell Mixing Zone Expert System (CORMIX) is software for analysis, predicting and nature of toxic wastes, saline, thermal or simply floating waste in water bodies. Near the aperture (or holes) of the outfall exit, the mixing process in the tube direction given the flow exit speed and that one of vertical mixing given according to the floatability (positive or negative), prevails on advection effect provoked by marine currents existing in the area. In the present work, it is about analyzing environmental factors and the outfall design which influence on brines dilution. First of all, and concerning the sea floor, effect of aperture height of outfall discharge is discussed, in keeping a configuration type of outfall and with average environmental speed of 5 cm/s. The environmental speed influence in dilution is evaluated, then analyze effect of the current exit speed on the dilution and, finally, the dilution with different configurations of multiple diffusers.

Conditions of the study

The initial technical parameters of the discharge by under-sea outfall of Fouka's desalination plant, which are taken into account in order to carry out simulations in different oceanographic characteristics situations of this Mediterranean area, are as follows in Table 3.

As for environmental conditions of the receiving water, due to a lack of data, it was not possible to analyze density profiles types of clean water column of winter, summer and end of spring seasons, in which is possible to set up a pycnocline at these depths in latitude of this area. However, a simulation of different values of the current velocity which affects the jet or the spilled plume has been made in demonstrating the worst conditions for waste dilution. The current direction in all analyses is parallel to the coast line that means in following approximately the East-West line, with in mind that is the current value shared vertically in two. In all analyzed cases, it is supposed a wind velocity of 2 m/s (recommended value from the point of view of safety for design of this installation type). First of all, it was studied effect of the discharge aperture height concerning the floor and tilt of jet outlet; by maintain the outfall geometry and an average environmental marine current speed of 5 cm/s as follows in Table 4.

Secondly, dilution analysis with different environmental marine current speed is performed. Then, study on effect of flow exit velocity with the same configuration and environmental speed the most unfavorable have been examined. Finally, different dispositions of multiple diffusers are evaluated, assuming the worst conditions of environmental speeds which may occur and so the previous geometrical configuration (depth and height of aperture on the floor).

CASE OF SIMULATION

Stack height

In (Fig. 6), graph shows dilution for two heights of stack from different floors, corresponding to 1m and 3m, by keeping the same average depth of 10 m. These limits are made to avoid pipes burial and optimize effect on dilution of water-body set above the waste point. The environmental current velocity is of 5 cm/s. The best dilution condition observed is given by heights from upper floors (H1=3 m), that means as waste aperture height is larger concerning the sea floor, best will be its dilution.

The CORMIX model does not allow that aperture's height on the floor be larger than the third part of the total depth located in the waste zone.

Table 3. Effluent characteristics poured by under-sea outfall of Fouka's desalination plant. Source: Fouka's desalination plant.

Parameters	Value
Reject salinity	69.53 g/l
Initial salinity	39 g/l
Salinity Variation	35.500
Poured flow	1.56 m^3/s
Diameter	1.4 m
Discharge velocity	1 m/s
Diffuser number	1

Table 4. Characteristics and outfall geometry Source: Personal work.

Parameters	value
Depth in waste aperture	10 m
Diameter of outfall	1.4 m
Flow exit speed	1 m/s
Poured flow (vertical)	1.56 m^3/s
Calculated water salinity	39.38 g/l
Initial concentration	35.50 g/l
Sea water salinity (20°C)	28.1 kg/m^3
Effluent Salinity (20°C)	55.1 kg/m^3

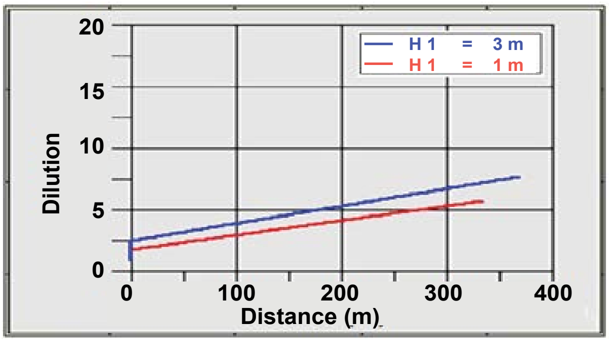

Fig. 6 Graph of dilutions according to different stack heights.

Diffuser inclination

(Fig. 7) shows dilution for two diffuser inclinations while maintaining the same average depth of 10 m. In these calculations, the environmental current direction is hold perpendicularly to direction of the effluent output flux. The best dilution condition is given by inclination of 45°C of the diffuser aperture. The angle of 90°C shows that waste is done in the vertical.

Influence of environmental speed and flow output speed

Here, it is studied dilution of brine waste with different environmental currents speed, if we consider magnitudes of recorded speeds in the area. No distinction is made between East and West trajectory of hyper saline waste plume due to the fact that in simulation, results are symmetrical in both directions. (Fig. 8) represents dilutions in different velocity cases and with geometry outfall and conditions of fixed discharges. The worst dilutions conditions are with speeds comprise between values of 2 cm/s and 5 cm/s, while with very high speed, dilution improves, considering the turbulent mixing process. Consequently, speeds of 2 cm/s are considered as the worst for dilution as follows in Table 5.

Influence of different diffuser diameter

(Fig. 9) shows dilution for three different diameters corresponding to output speed of de 1 m/s (D1=1.3 m), of 2 m/s (D2=0.92 m) and of 3 m/s (D3=0.74 m) in maintaining the same average depth of 10 m, height of 3 m of the waste aperture on the floor and an environmental speed of 2 cm/s. It is observed that the best condition of dilution is given by higher speeds of output flow by waste outfall and, consequently, by lower diameters of outfall aperture.

Simulations summary

In the light of the results of the diffusion study by modelling with CORMIX program in different conditions, the main recommendation and mitigation measure of rejects effects is the construction of the discharge channel (Outfall design) of the desalination plant (Fig. 10) by respecting the recommended variant in the following Table 6.

Knowing that outfall is composed of a pipe of DN1400 in PEHD of 500 m length. That one is shifted of 300 m to the intake' East. It should be noted that currents are from West to East, the plume created by the outfall will be thus far of the water intake.

The simulations of Delft-3D model have been carried out with results of CORMIX as input for audit model and design in the far-field (Akar and Jirka, 1994a; Akar and Jirka, 1994b; Pun and Davidson, 1999). The far-field Delft-3D model uses a nested rectilinear grid model with horizontal grid spacing. The fine mesh grid covers diffusion area with CORMIX effluents concentrations located on a Delft-3D grid to represent the near-field mixing. Results of the model show that, generally, the impact of discharged effluent on intake is negligible in all cases taken into account. As previously reported, only the far-field model which provides analysis confirmation of the near-field mixing area, manage diffuser design and so type, size and diffuser supports, angle and discharge spot spacing. It should be noted that approach to combine results of near-field simulations in the far-field model is not dynamic and is treated as being an off-line input channel.

Changes in ambient conditions of near-field of the mixing zone after each tide stage are not taken into account in far-field model. Furthermore, and to a

Environmental speed (cm s-1)	Distances of waste point (m)				
	100	500	1000	4000	10000
2	3	8	11.8	16	29.4
5	5	6,1	8.4	30	106
10	5	7,6	12.8	139	1.315
20	7	12	60	1.100	3.000

Table 5. Dilution values at different distances of waste point and by different sizes of the environmental speed. Source: Personal work.

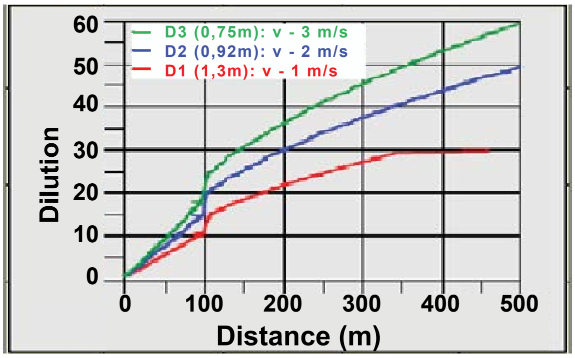

Fig. 9 Dilutions graphs according to different diffuser diameters.

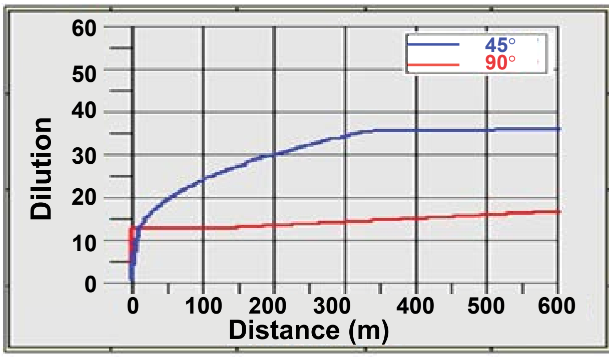

Fig. 7 Graph of dilutions according to different diffuser inclinations.

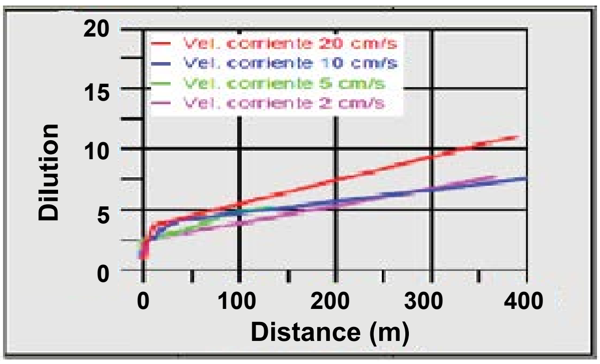

Fig. 8 Dilutions graphs according to different sizes of environmental speed to distances lower than 400 m from waste point.

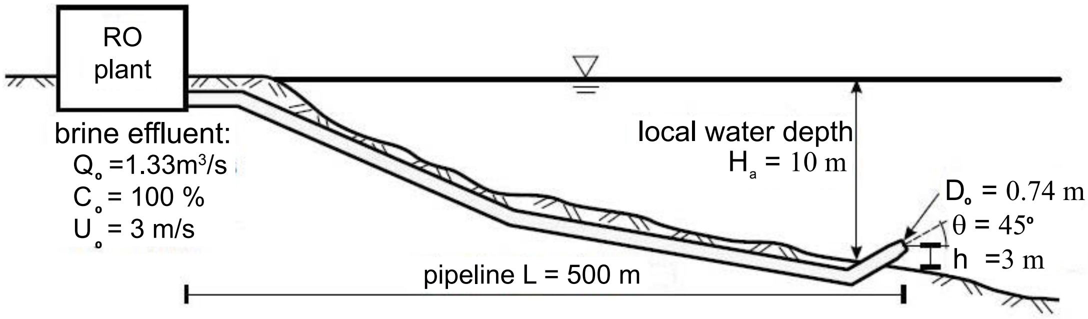

Fig. 10 Outfall design (CORMIX) Source: Personal work.

Table 6. Characteristics of recommended variant Source: Personal work.

Parameters	value
location coordinates UTM X and UTM Y	319.517 m and 4.084.942 m
Waste point depth Ha	10 m
Height of waste aperture on the Funds h0--	3 m
Diffuser diameter D0	0.74 m
Design flow Q0	1.33 m^3/s
Output speed U0	3 m/s
Inclination of diffuser aperture ɵ	45°
Length of outfall pipe L	500 m

limited extent, a quasi transitional treatment of tide cycle in the near-field model represents concentration accumulation in constituents during tide reversal (Jirka, *et al.*, 1996). The diffuser system design depends thus of the selected conservative dilution factor in the near-field model. Consequently, the concentration importance accumulated during tide reversal on several tide cycles has not been accurately modeled in the near-field model (CORMIX).

CONCLUSION AND RECOMMENDATIONS

The present document presents a study's case of the diffuser design system in sea coast to meet criteria of the effluent mixing area. The modification proposed in the environmental impact assessment study that include the discharge of previously diluted brine into the Fouka Channel, has minimised the impact of the discharge on the environment, has encouraged the rapid dilution of the brine, and moved the discharge away from the sea grass meadows. The CORMIX mixing model is used to evaluate the mixing model process of the near-field of the plant's effluent. The Delft-3D is used for the far-field of the mixing area and only as a confirmation analysis taking input from the near-field model. The values of characteristics of the recommended variant mentioned in Table 6 reflect an adequate dilution reducing impact of brine concentrate on the environment. In order to accurately determine dispersion, recalculating and the environmental impacts of brine reject plumes, it is important to be able to model in detail the different characteristics of outfall plume, of near-field (small scales, meters around of reject point) to the far-field (large scales, until several kilometres away). Each model has a limited validity field which should be known by its users. In order to reach reliable results through a model, gathering calibration and ground data of good quality are necessary (Zhang and Adams, 1999). For this reason, the field measurement campaigns on the ground must be designed and carried out in such a way the input data and model calibration would be as accurate as possible. It is therefore imperative to achieve a bathymetry of the study area, an investigation on biological and ecological nature of ocean floors and a census of fishing zone (professional and pleasure fishing) near the study area. However, if this model is well adjusted and if input data are of quality, it becomes a powerful and reliable management tool.

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