REPORT Nº 03: DIFFUSER DESIGN - INITIAL DILUTION STUDY

Document history:

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ÍNDICE

1. INTRODUCTION

This document was written to study the dispersion in near field of brine discharged by the Aqaba SWRO Desalination Plant, with a 300 M m^3/year capacity for two conversion rates: 42% & 45%.

In the near field (initial mixing area) where the highest hypersaline discharge dilution is achieved mainly due to the turbulent phenomena associated with the quantity of movement transferred with the discharge. In this region, the initial dilution process mainly depends on the **discharge parameters** (diffuser type, number of outlet ports, diameter of the outlet ports, etc.) meaning this is the process where the designer can work to improve the discharge dilution.

Once the possible scenarios have been analysed and the design criteria established, the brine discharge for different alternatives will be modelled by **BrIHne-Jet-Spreading model.**

2. SCOPE OF WORK

The aim of this study is to design the diffuser to **fulfil with environmental regulations.**

Two scenarios are modelled considering:

- Case 1 - Desalination plant overall recovery 42%
- Case 2 - Desalination plant overall recovery 45%

3. MODEL DESCRIPTION

A widely contrasted model for near field study shall be used: **brIHne.**

"BrIHne" 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. (2012, a, b). Conclusions revealed significant shortcomings and a poor agreement with experimental data when simulating this type of disposals.

To overcome the commercial model´s shortcomings and with the aim of having more feasible models that can be constantly improved and updated, the Environmental Hydraulics Institute has developed the "brIHne" tools.

These tools are based on dimensional analysis and integration of differential equations with mathematical approaches scientifically supported. They have been designed with an optimized interface, very intuitive and easy to use. BrIHne models have an instantaneous execution and once run, a "pdf" report is provided, including the flow main variables evolution to characterize the discharge behaviour. Plots are also an output of the models to better understand the results.

An important advantage of "brIHne" discharges is the re-calibration with experimental data obtained by tests carried out in IH Cantabria by the use of nonintrusive optical laser techniques PIV (Particle Image Velocimetry) and PLIF (Planar Laser Induced Fluorescence). These techniques allow obtaining synchronized velocity and concentration values within the flow with a high quality and a large spatial and time resolution. 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.

In the end, the **brIHne-Jet-Spreading** model will be used since it simulates the behaviour of the flow in the complete near field region including not only the jet path but also the spreading layer, which makes it possible to establish the initial conditions (speed and concentration profiles) for coupling with the far field model.

The BrIHne-Jet-Spreading model applies the dimensional analysis formulas presented by Pincince et al. (1973), and later by Roberts et al. (1987) for jets. For the spreading layer, formulas are used as presented by Roberts et al. (1997). These formulas have been generally used to characterize the behaviour of flow at unique points along the path such as the maximum height or impact point on the bed or the end of the near field.

Moreover, the results of the model were validated with experimental data published by other authors (Roberts et al. (1997), Cipollina et al. (2005), Kikkert et al. (2007), Shao et al. (2010), Papakonstantis et al. (2011a), Papakonstantis et al. (2011b), for all discharge angles simulated by the model. The validation shows very good correlation between the numerical results of brIHne-Jet-Spreading, especially as refers to the characteristics of the jet at the maximum height, point of return, and end of the near field (spreading layer), and the experimental data published by various authors.

What follows is a sample diagram of the outfall in the model where the flow axis is represented with a dotted line. The concentration axis (X, Zc) is defined as a line that joins the maximum concentration points of each flow section. Moreover, the variables are shown at the characteristic points in the flow path.

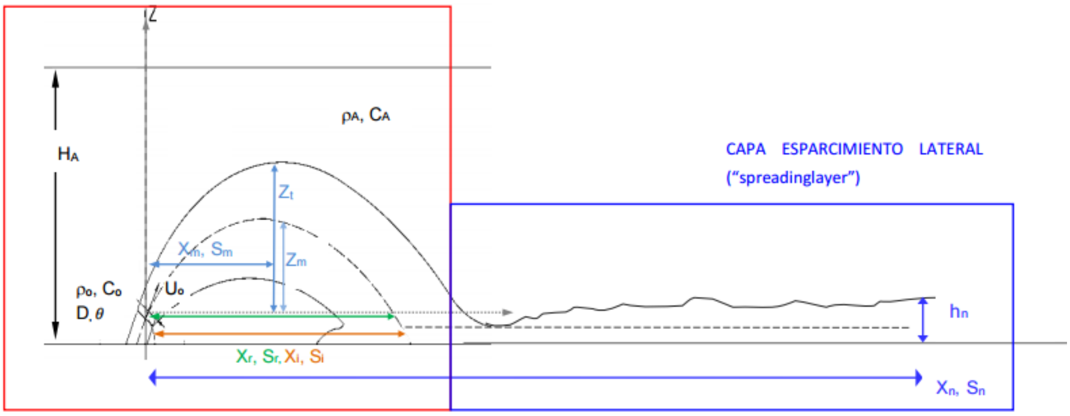

Figure 1. Diagram of the outfall simulated by the Brihne -Jet- Spreading model

In this case, a single discharge outlet will be simulated with the corresponding flow for that outlet. Once the discharge outlet is modelled based on the plume width, a separation between outlets will be defined to guarantee there is no mix between contiguous plumes.

4. INPUT DATA

4.1. AMBIENT CONDITIONS

According to the baseline data, the following values were taken into account:

Ambient conditions	
Salinity	Temperature
40,80 g/l	**28 ºC**

From the previous data, the density obtained for seawater is **1,026.67 kg/m3**

4.2. BRINE EFFLUENT CHARACTERISTICS

Following the desalination process study by the plant engineering team, the design data for the brine effluent is as follows:

	Brine effluent characteristics		
	Brine flow	Salinity	Temperature
Case 1 – overall recovery 42%	**48,756 m3/d**	**70.345 psu**	**29º C (ambient + 1 deg C)**
Case 2 – overall recovery 45%	**43,152 m3/d**	**74.18 psu**	

The resulting brine densities are **1,048.73 kg/m3** and **1,051.68 kg/m3** respectively.

4.3. DIFFUSER SET-UP

The following diffuser configurations have been considered as an input to check the brine model dispersion in the near-field region.

4.4. CASE -1 OVERALL RECOVERY 42%

Diffuser system features -Case 1	
Parameters	
Number of Diffusers	30
Diameter of the Diffuser Port (ID):	300 mm
Velocity of each diffuser:	6.40 m/s
Separation between diffusers:	15.5 m
Diffuser angle to the horizontal:	60 º
Depth of seabed at the diffusers	- 25 m

As can be seen, 30 outlet ports with an ID 300 mm comprises the diffuser system. Each port is separated 15.50 m (total length of 217 m). Outlet ports are arranged by pairs, back to back.

4.5. CASE -2 OVERALL RECOVERY 45%

Diffuser system features -Case 2	
Parameters	
Number of Diffusers	30
Diameter of the Diffuser Port (ID):	300 mm
Velocity of each diffuser:	5.65 m/s
Separation between diffusers:	12.70 m
Diffuser angle to the horizontal:	60 º
Depth of seabed at the diffusers	- 25 m

Same concept is used for case – 2 diffuser set-up in terms of total number of diffusers and outlet port inner diameter.

4.6. ENVIRONMENTAL REGULATIONS

According to the environmental regulation at the zone, the **maximum admissible increase of salinity** concerning ambient salinity (seawater) is **2%** at 100 m from the discharge point.

Considering the most restrictive recovery case, the initial dilution required can be calculated by the following expression:

$$Sfinal = Sinic + \frac{(Sefl - Sinic)}{Di}$$

Where:

- Sinic = Initial salinity (40.80 psu)
- Sefl = Brine salinity (74.20 psu)
- Sfinal = Final salinity (40.80 psu + Δ2% = 41.62 psu)

Therefore, the minimum initial dilution to be achieved is **1:40.90**

5. CALCULATION AND RESULTS

The previous diffuser set-up for both cases has been studied to check whether complying with the environmental regulation previously indicated, taking into consideration the minim initial dilution to be achieved.

Results for both cases are summarized below:

5.1. CASE – 1 OVERAL RECOVERY 45%

Near-field modelling was carried out considering all input data given. The diffuser design stated above was considered to check whether comply with excess salinity requirement at the end of the near field region.

For this case, the **dilution achieved is 1: 68.60** at the end of the near filed region (spreading layer) which is higher than required.

The resulting horizontal location of the spreading layer at the end of the near field region is 68.60 m from the discharge point. Further from this boundary the far-field region begins, where the hydrodynamic forces (currents, wind, etc) take their place and govern plume behavior.

Moreover, the salinity obtained at the same point is 41.20 psu which represents an increment of **1.06%** concerning seawater salinity, resulting lower than the admissible salinity (2% more than ambient salinity, i.e 41.616 psu).

Therefore, compliance with Environmental regulations is justified.

A brief summary of modeling results is shown in the following table:

					brIHne Results						
					Jet flow behavior				Spreading layer flow behavior		
Nº ports	θ(º)	ID(mm); SDR 26	Flow per diffuser port(m3/s)	V (m/s)	dilution	Xi (m)	Hmax (m) relative to port nozzle	R=2B	dilution	Xn (m)	Sal,max (psu)
30	60	300	0.45	6.40	35.80	28.22	19.90	8.30	68.60	68.63	41.23

where:

- Nº ports, the number of outlet ports,
- Θ, the angle with the horizontal line,
- ID, the inside diameter of the outlet port,
- V, the jet output speed,
- Dilution (jet flow behaviour), centerline dilution at the impact point.
- Xi, centerline horizontal location of the impact with bottom point.
- Hmax, the maximum jet height, relative to port nozzle.
- R, the radius of the plume,
- Dilution (spreading layer flow behaviour), centerline dilution of the spreading layer at the end of the near field region.
- Xn, the horizontal reach of the spreading layer.

As can be seen in the previous table the plume´s radius (radial distance from the certerline to where concentration is 6% of that at the centerline) is 8.30 m. The following graph illustrates it:

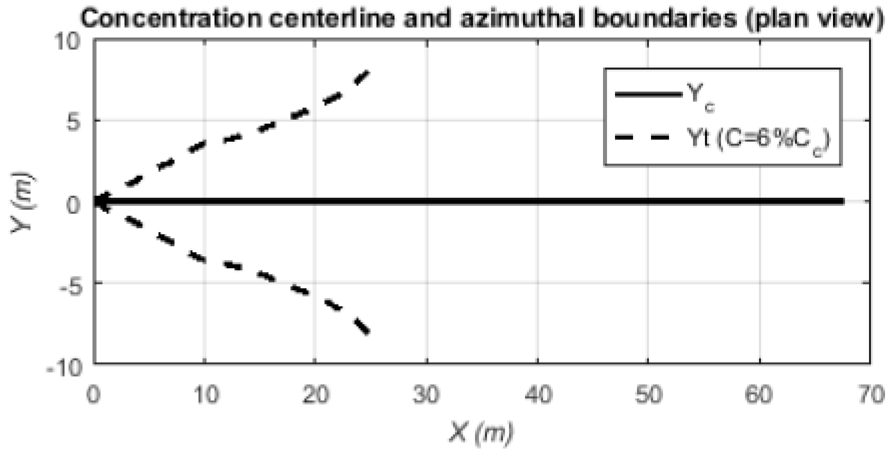

Figure 2. Plume´s radius case 1. Plan view.

Thus, as the separation between outlet ports is more than 9.60 m, no merging between discharge plumes are expected, otherwise, if plumes are merged the resulting dilution will be affected.

Further details concerning the plume behaviour are included in **addendum 1.**

5.2. CASE – 2 OVERAL RECOVERY 42%

For this case, the **dilution achieved is 1: 56.90** at the end of the near filed region (spreading layer) which is higher than required.

The resulting horizontal location of the spreading layer at the end of the near field region is 56.93 m from the discharge point. Further from this boundary the far-field region begins, where the hydrodynamic forces (currents, wind, etc) take their place and govern plume behavior.

Moreover, the salinity obtained at the same point is 41.38 psu which represents an increment of **1.44%** concerning seawater salinity, resulting lower than the admissible salinity (2% more than ambient salinity, i.e 41.616 psu).

Therefore, compliance with Environmental regulations is also justified.

A brief summary of modeling results is shown in the following table:

					brIHne Results						
					Jet flow behavior				Spreading layer flow behavior		
Nº ports	**θ(º)**	**ID(mm); SDR 26**	**Flow per diffuser port(m3/s)**	**V (m/s)**	**dilution**	**Xi (m)**	**Hmax (m) relative to port nozzle**	**R=2B**	**dilution**	**Xn (m)**	**Sal,max (psu)**
30	60	300	0.40	5.65	29.70	23.40	16.51	6.90	56.90	56.93	41.38

Likewise, the adopted separation between diffusers is higher than the resulting plume´s radius (6.90 m according to model results). Consequently, no merging between continuous discharging ports is expected.

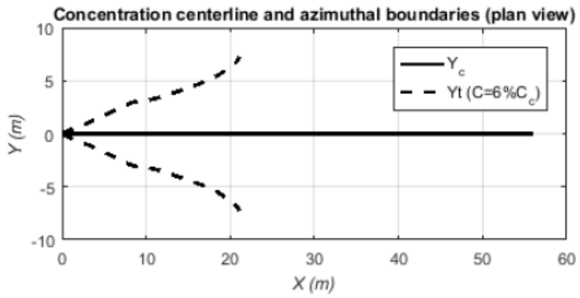

Figure 3. Plume´s radius case 2. Plan view.

Further details concerning the plume behaviour are included in **addendum 2.**

ADDENDUM 1:
BRIHNE MODEL RESULTS. CASE -1

ADDENDUM 2:
BRIHNE MODEL RESULTS. CASE -2