International Journal of Advanced Engineering, Management and Science (IJAEMS)
Peer-Reviewed Journal
ISSN: 2454-1311 | Vol-8, Issue-7; Jul, 2022
Journal Home Page: https://ijaems.com/
Article DOI: https://dx.doi.org/10.22161/ijaems.87.3

Review on Hydrodynamic Modelling of Desalination Plants Brine Effluent Marine Outfalls

Yasser Elsaie[1], Hoda Soussa[2], Mohamed S. Gado[3], Ahmed Balah[4]

[1]Associate Professor of Coastal Engineering and Shore protection, Head of Civil Engineering Department the Higher Institute of Engineering Elshrouk City Cairo, Egypt.
[2]Professor of Water Resources Engineering Faculty of Engineering, Ain Shams University, Cairo, Egypt.
[3]Teaching Assistant at The Higher Institute of Engineering Elshrouk City Cairo, Egypt, Phd Student, Irrigation & Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.
[4]Assistant Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

Received: 12 Jun 2022; Received in revised form: 09 Jul 2022; Accepted: 13 Jul 2022; Available online: 17 Jul 2022

Abstract— *This paper presents a review on hydrodynamic modelling of desalination plants brine effluent marine outfalls. Brine effluent is a byproduct of desalination plants that must be safely discharged with little environmental impacts. Several researchers have been studying the behavior of brine effluent disposal to the sea using marine outfalls but due to its complex behavior yet it is not completely understood, where the international design standards and specifications are limited and there is no unified design approach for the marine outfalls. The dilution and dispersion ability of the ambient water body are discussed. The outfall inclination angle and current speed are also investigated.*

Keywords— ***Hydrodynamic modelling, Brine effluent, Marine outfalls, Dilution.***

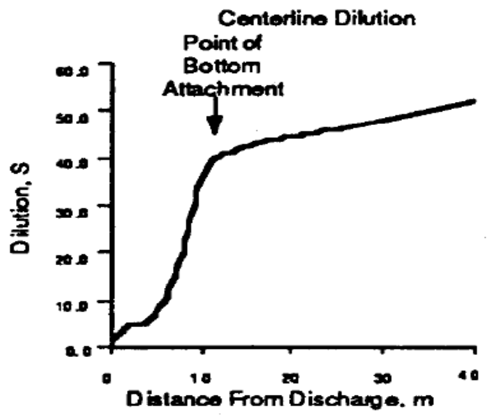
I. INTRODUCTION

One of the major pillars for maintaining human and other biological life on earth is the availability of water. In most arid, and semi-arid coastal zones, water demand is rising for the urban and industrial sectors, forcing planners to find new, alternative, and renewable water resources. Additionally, because fresh water sources are so far away from coastal communities, bringing fresh water there is exceedingly expensive and complicated. The desalination process has emerged as one of the most viable and promising alternatives for supplying fresh water to numerous industries, particularly those in water-stressed locations such as coastal areas. Brine effluent is a byproduct of desalination technique that must be safely discharged with little environmental impacts. This hyper saline water is discharging to the marine environment using outfalls in a turbulent jet form with density higher than the density of the receiving water body which more the allowable limit 10 %. The design of marine outfalls has not been coved yet and there is a need to have a unified design approach for these outfalls that leading to safely discharging of hyper saline water from desalination plants.

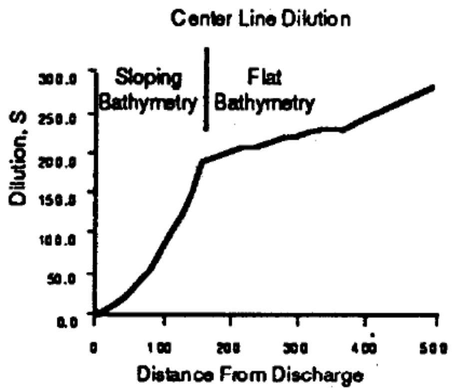
II. PREVIOUS STUDIES

J.V. Del Benel et all (1994) [1] Studied the effects of brine discharge to the ocean using CORMIX software, and the findings indicated that thick brine discharges can have an influence on the benthic ecology. A cautious recommendation for preliminary research to reduce the impact of brine effluent to the ocean is an effluent dilution to 1 ppt above ambient. Dense brine effluents can be diluted to 1 ppt over acceptable distances. The CORMIX program may be used to forecast how brine discharges will spread out as demonstrated in fig. 1 (a), (b).

Vlado Malacic (2001) [2] Conducted a numerical model to study the initial dilution of sewage discharging from a diffuser into stratified waters in the Bay of Piran northern Adriatic. The starting tilt of a buoyant jet has a minimal impact on dilution but a substantial impact on rise height, according to model simulation results. The discharge velocity, on the other hand, has a significantly greater effect on the dilution than on the rise height. The model also demonstrated that plumes, which originate from orifices spaced about 10 m apart, remain well separated until they reach a layer of neutral buoyancy below the sea surface in a calm sea with normal summer stratification.



(a)



(b)

Fig. 1. Dilution with downstream distance for submerged (a) and Surface (b) discharge.

Merih Ozcan, and Dr. K. Tunc Gokce (2002) [3] Made Numerical model using MIKE21 for case study outfall design in turkey to assess the pollution impacts of the imposed water quality. For estimating effluent dilution average current speed value is used at many outfalls design. Choice of those average values depend on random observations that are typically insufficient in terms of sample quantity and monitoring time. For model calibration limited period of 4 weeks total duration field measurements at 4 different locations around the discharging outfalls were mainly observed. CORMIX and the MIKE21 advection-dispersion model were combined. For far-field modelling, the initial dilution and close field temperature gradient were initially determined by CORMIX, and the outcomes were then converted into MIKE21.Using numerical models are a very lately started in outfall design projects in Turkey. The results showed that with the usage of numerical modeling, it may be viable acquiring greater records at the oceanographical situations of the layout place even if the sphere facts are limited.

Thomas Hoepner*, Sabine Lattemann (2002) [4] A field study for desalination plants chemical impacts at the northern Red Sea was made to present unique transferable results. Brine consists of many hazardous compounds such as chlorine, copper, and antiscalants additives That, have various ecological destiny. Effects of chlorine and copper will appear near to the outlets, then diminished due to chlorine dilution, and copper transport into sediments. However, concern from these compounds must still be expressed due to chlorine's extreme toxicity and the harm posed by copper enrichment in sediments, but low environmental risk of antiscalants from MSF and RO plants. Because of negligible terrestrial runoff at the Red Sea especially at north antiscalants has a major drawback of poor degradability that requires more investigation. Due to its geographical isolation, the Gulf Aqaba one of the most sensitive sites for brine effluent, leaving pollutants with little diffusion and adversely affecting marine life and habitats. About 7 million m3/d of installed saltwater desalination capacity, or half of global capabilities, is located in the Arabian Gulf. The plants get feed water from a body of water that is influenced by the upstream plants in the Red Sea, and the Arabian Gulf offers better flushing conditions than the Red Sea. The risk of ecosystems damage in close to plants outlets is at hand. However, landfill activity has more imminent effects that destroys the shallow water as described in Tarut Bay.

The Red Sea must be considered a rare ecological treasure that is susceptible to environmental damage. So that, information maps about plant locations can be created that are a useful tool for studies of environmental impacts.

Anton Purnama et all (2003) [5] developed a numerical model to simulate the dispersion of brine discharges from a coastal desalination plant at Oman. Coastal desalination plants in Oman discharge the brine waste containing excessive salt awareness into the sea. Continuously discharging brine wastes immediately at the coastline will bring about the salinity expanded alongside the coastline. The effect of brine disposal operations on coastal and marine environments may be prevented with the aid of using extending the outfalls in addition offshore to the sea.

Y. Fernandez-Torquemada et all (2005) [6] Made an experimental study to show the monitoring of the brine discharge, on time and space, from the reverse osmosis (SWRO) desalination plant, which began operation in September 2003, in Alicante, SE Spain. Three surveys have been done in February, April and August 2004. With the aim of defining the brine plume and its dilution along the area, a grid of more than 100 sample stations was erected at the brine discharge point for each campaign. With a measuring range of 0–70 psu and a precision of 0.01 psu, salinity measurements were obtained from surface and bottom water at each station. After the results of the first survey, the grid was extended to cover a larger area. Using the kriging approach, the data received from each campaign was interpolated. The USEPA's Geostatistical Environmental Assessment Software was employed. One year after the plant's start-up, the findings of these campaigns have demonstrated that the brine's dilution may be less than generally believed, which may have a substantial impact on the lengths of marine ecosystems. The data gathered in this study can be deemed extremely helpful for use in applying to upcoming projects in the Mediterranean Sea.

A.M.O. Mohamed et all (2005) [7]] Study the groundwater resources degradation in the Al Wagan, Al Qua'a, and Um Al Zumool areas of eastern Abu Dhabi. To gather information regarding the quantity and quality of groundwater, brine, and pond water, they created a questionnaire for the plants that were being inspected. He also examined the three plants' water samples and collected soil samples from the Al Qua'a dumping site and two adjacent locations. The physical, chemical, and total petroleum hydrocarbons (TPH) content of water samples and the physical, chemical, and mineralogical composition of soil samples were both evaluated. There were no groundwater samples taken in the vicinity.

The results showed that

1. The potential of salty water incursion into fresh water increases when brine is disposed of in unlined ponds or pits, which can cause serious problems for soil and feed water.

2. Between 30 and 40% of the brine produced by the three units was rejected. A small increase in the percentage of salts and EC that were easily able to penetrate the groundwater was revealed by chemical analysis.

3. About twice as much TDS is present than in the feed water source. The greatest amount of TPH was found in the Al Quaa plant, whereas electrical conductivity and TPH levels increased in water samples from the Um Al Zumool RO plant.

4. An rise in TPH in desalinated water can has a quite danger on health.

Alameddine, M. El-Fadel (2006) [8] By taking heated effluent from a desalination-power plant in the Gulf area into consideration, a model employing CORMIX was developed to predict the dispersion of the brine plume in a marine environment. For this purpose, the brine characteristics, potential impact, operating conditions, and features of the area's hydrodynamics were reviewed. To identify the ideal outfall structure, various simulated scenarios for surface discharge, single, and multi-port diffusers were evaluated.

The physical, chemical, and biological qualities of the receiving water body might be harmed by brine disposal. The degree of degradation is highly dependent on the total volume of the brine, dilution rate, and the receiving water characteristics. The environmental effect of brine is also depended on the configuration of the discharge outfall. Gulf area have the large number of desalination and power plants in the world generating about 15,000 MW of electric power and 11.99×10^6 m3/day of desalinated water. The seawater of the Arabian Gulf differ from the world's ocean waters such as high salinity levels and high temperature that could exceed 45°C.

The brine plume caused by the continuous discharge of the MSF desalination and power plant was simulated using the CORMIX-GI model. For evaluating the environmental effects of point source discharges within their mixing zones, the United States Environmental Protection Agency (USEPA) has authorized simulation and decision support system known as CORMIX. To examine the efficiency and mixing behavior of surface, submerged single-port, and multi-port outfalls into the shallow water characteristic of the Arabian Gulf, three fundamental scenarios were run. Results demonstrated the insufficiency of employing surface discharge outfalls for salt disposal while simulating the dispersion of a brine plume from a desalination power plant in the Gulf area. A tenfold dilution rate was attained within a 300 m mixing zone, demonstrating that the use of multi-ports was sufficient to improve dilution rates and reduce any possible environmental consequences as shown in figs 2,3.

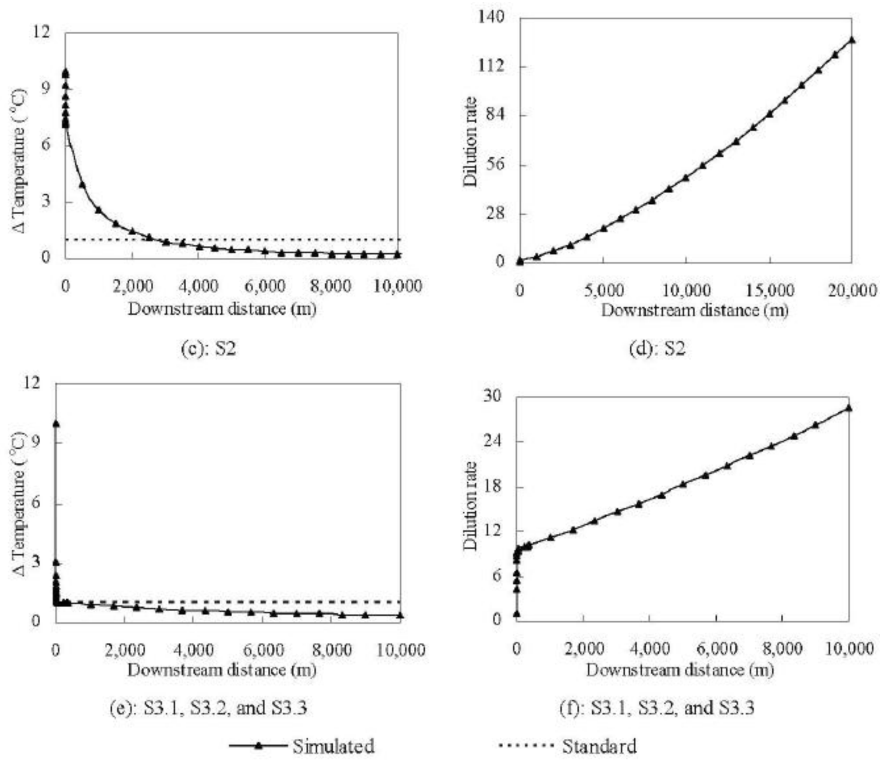


Fig. 2 Drops in temperature and dilution rates with downstream distance for different simulated scenarios.

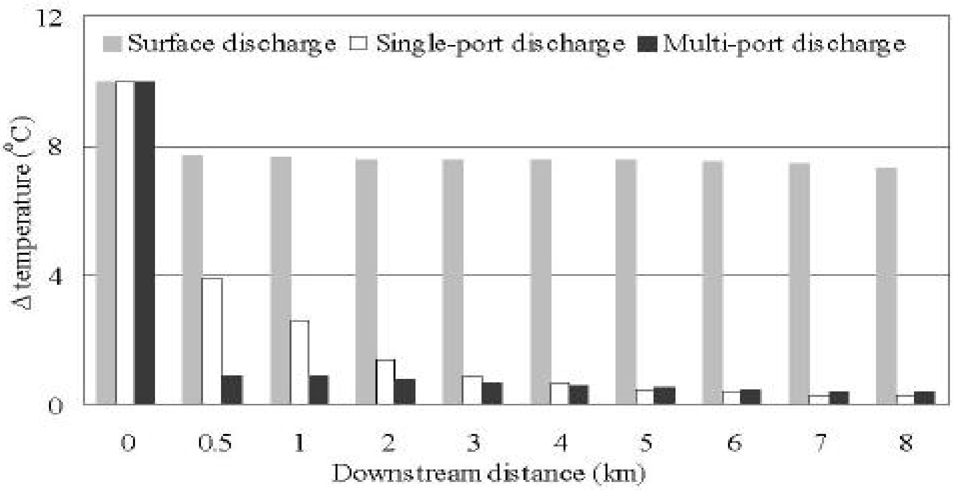


Fig. 3 Plume temperature drop Comparison between surface, single and multi-port discharge.

Haibo Niu, et al. (2007) [9] In order to provide a tool for probabilistic study of the mixing of generated water in the marine environment, the PROMISE model was created. They go into detail about how laboratory results and other models were used to validate PROMISE's near field module. Three distinct forms of buoyant jets from three separate data sources have been compared to the model predictions for buoyant jet trajectory, plume diameter, and dilution. Statistics have been produced comparing the expected and measured values. The results demonstrate that PROMISE can accurately predict all three parameters, and its level of bias is equivalent to that of other models. Although PROMISE's mean prediction errors are a little bit lower than those of other models, most of their ranges are a little bit bigger.

H.H. Al-Barwani*, Anton Purnama (2007) [10] To explore the environmental impact and how we may reduce it, a mathematical model of brine plumes discharged into seawaters using a two-dimensional diffusion equation were constructed. Because the tidal current dominates the flow in the sea, the brine effluent will be transported away from the outfall, and then will be returned to the outfall when the flow reversed. It's possible that the plume returned to the outfall three times before finally departing it. Due to constant rate continuous discharge, then the near field coastal water at the reversal flow, when the flow speed and dispersion drops to zero will have an unacceptable high concentration salinity.

Generally, because of a lack data on the impacts of desalination plants on the marine ecosystem to evaluate these impacts for regulatory and design purposes. Higher salinity expected near the outfall, and plume drifting along the coast has been observed. Environmental risks can be reduced by limiting brine levels using several treatment techniques or by assuming maximum concentration limit and the effect of oscillating tide flow on mixing brine outflows should be investigated using a two-dimensional diffusion equation. Maximum concentration on the beach remains constant throughout the tidal cycle, that can be used as an impact measure. Finally, Xmax is observed as a long distance downstream the outfall, increasing as the values of model parameters increase, Cmax can be expressed as

$$\text{Cmax} = \frac{\alpha}{X_{max}+\cos T}\sqrt{\frac{8\pi\eta}{e}}. \quad (1)$$

Cmax maximum concentration, α = 0.4, T = π and 2π of a tidal cycle.

Kikkert et al. (2007) [11] The behavior of inclined negatively buoyant jets was predicted analytically, and good agreement with data for beginning discharge angles ranging from 0 to 75 deg and initial densimetric Froude values from 14 to 99 was achieved.

Blue Hill Hydraulics Incorporated (2007) [12] developed a CORMIX hydrodynamic model to calculate the size of the thermal plume produced by the Calvert Cliffs and to calculate liquid effluent dilution factors as shown in fig 4. The results showed that 0.5 C more than ambient temperature at the end of mixing zone. The calculated dilution time assumes that the plume is not well-mixed 50-miles from discharge point, therefore, conservative, because it does not include the effect of tides which could increase mixing. According to this analysis the plume does not contact the shoreline of the Chesapeake Bay.

Esperanca Gacia et all (2007) [13]] made a field study to study the impact of the hypersaline water on ecosystems. This study conducted in the Mediterranean to study the effect of brine on a shallow Posidonia oceanica meadow for more than 6 years. Posidonia oceanica has proven to be extremely vulnerable to eutrophication and high salinities derived from the brine discharge. The results demonstrate that under field conditions Posidonia oceanica is extremely susceptible to brine discharges from desalination plants. The study concluded that salinity above 39.1 has an impact. Therefore, in order to protect these ecosystems, effort should be made to dilute saltwater significantly before it reaches seagrasses.

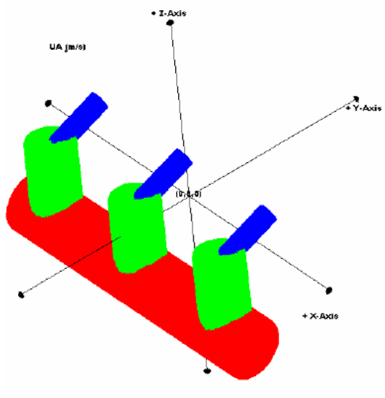


Fig 4. Diffuser configuration

Jochen Kämpf (2009) [14] investigated the mid-field dilution of blended desalination brine discharged into a tidal sea using a high-resolution three-dimensional hydrodynamic model. Any additional sources of turbulent mixing, such as storm occurrences, residual circulations, or wind waves, were neglected in favour of forcing the model using a salt flow dispersed across a predetermined starting mixing volume. The results showed that:

1. The blending strategy may reduce salinity consequences, but it may also result in less dilution near the discharge area, which might be harmful to the marine benthos inside the mixing zone.

2. The degree of vertical density stratification of the water column and the horizontal breadth of the mixing zone both decrease as a result of the blending procedure. Saline underflow creation is less likely as a result, and other forces can help mix the water.

3. Increased discharge rates might cause diffusers' mixing effectiveness to change.

A. Etemad-Shahidi, et al. (2010) [15] A good way to dispose of hot water in coastal locations is to use numerical models to forecast the behavior of the plume. Multi-port diffusers are required for this procedure. In order to anticipate the initial dilution of multiport tee diffusers, this study created an application of artificial neural network modelling. Several networks with different structures were tested using error back propagation algorithm. A three-layer network with 9 neurons in the hidden layer is skilled at predicting initial dilution, and the outputs are in good agreement with experimental findings, according to the results of statistical error measurements. According to the sensitivity analyses, the diffuser's equivalent slot's width is the most crucial factor when estimating initial dilution.

P. Palomar et al. (2012) [16] predicted a numerical modelling based on data obtained from previous studies to improve the design and modelling of brine discharges outfalls, improve the numerical model's ability in the assessments of desalination projects environmental impact. The results showed that CORMIX1 and CORMIX2 employ relatively simplified formulas and are not valid for negative buoyant discharges, then the usage of CORJET, UM3 models is advised more for single port discharges.

Hesham El-Badry et al. (2012) [17] Delft-3D used for preparing hydrodynamic model to the Gulf of Aqaba to estimate the adverse effects of brine effluent disposed from desalination plants on the marine environment in the Gulf. The model is qualitatively confirmed rather than quantitatively calibrated since the findings for the current situation show that primary eddies are forming along the centerline of the Gulf, which is consistent with earlier research. A 6°C difference between the heated top layer and the chilly deep water, which ranges in temperature from 28°C to 21°C, was replicated by the model for the thermal stratification in July.

Model results showed that observed current speeds at the Gulf sides are larger than at the central part. The Gulf north end has 2 - 3 cm/sec current velocity. The density current was discovered to be caused by brine discharged closest to the bottom, where the current velocity was discovered to be greater than at the surface. Marine ecologists must examine the model findings to determine any potential effects on the marine ecology in the GOA. The GOA hydrodynamic model is currently in its early stages of development and needs further work for improvements. Due to a paucity of meteorological measurements, the present version of the model did not take the surface heat fluxes into account.

Candela Marco-Méndez, et al. (2012) [18] Performed a numerical analysis for the desalination plants at Nuevo Canal de Cartagena (Spain), which release dispose hypersaline effluent through a submerged outfall pipeline producing a negatively buoyant brine jet. The prediction and control of brine discharges include the use of several near-field mixing models, however these models are seldom compared to field salinity measurements taken inside the brine jet. These field measurements were taken by two divers, who then compared them to predictions made by the CORMIX1, CORJET, MEDVSA, and UM3 mixing zone models. Except for UM3, whose prediction provided the best match to observed data, each model's results were often fairly conservative. It is stated that while assessing the precision of present models or creating new near-field mixing models, direct field observations should be crucial.

Yasser Shawky et all (2012) [19] Conduct a physical model to study the effect of banha thermal plant outfall on El-Rayah El-Tawfiki. High temperature decreases oxygen concentration in the water which is very important for aquatic life. This phenomenon will be critical in study area with the construction of Banha Power Plant. A physical model was built for designing the intake/outfall to meet with the Egyptian regulations. With using open channel for discharging cooling water 4500 m2 around the outfall has 5^° c above the ambient temperature, that led to dissolved oxygen value less than 7 mg/L which considered a critical value. With using 24 nozzles multi-port outfall the mixing process improve that led to only 600 m2 with raised temperature to 5^° c that considered a small area with low effect on the aquatic live.

CARLOS PALACIO, et al. (2013) [20] A near field dilution model and hydrographic data from salinity, temperature, and density profiles, as well as from the velocity data at different levels of the water column, were used to determine the dilution, trajectory, and thickness of the buoyant plume formed by wastewater discharge from the submarine outfall of Santa Marta. An earlier run of a three-dimensional hydrodynamic model gave the velocity's magnitude. According to the upwelling and stratification characteristics of the receiving body of water, the results demonstrated that the plume experiences alternate phases of being trapped in the water column or reaching the ocean surface. Dilution levels beyond 100, and occasionally even up to 400, are attained when the plume reaches the surface. The plume is between 5 and 20 metres thick when it reaches the water's surface. In this case, the plume is diluted as it reaches the surface. Dilution reaches its maximum value of 10:1 when the plume is trapped and brought to neutral buoyancy by water column stratification. In these situations, the plume is kept imprisoned at depths of 25 to 47 metres without having an impact on the water's surface.

Sami Maalouf et all (2014) [21] Study the optimal design of RO brine outfall for a desalination plant located 168 miles south of San Francisco using CORMIX. They verified that, when employed appropriately, marine outfalls with multiport diffusers are quite effective in increasing the dilution levels of negatively buoyant plumes. They also demonstrated that optimization techniques by numerical models can be applied to minimize the total costs of these outfalls. Analysis of nearfield mixing procedures and SWRO brine flow simulations may both be done directly using CORMIX. Their findings show that it is possible to build cost-effective marine outfalls that maximize dilution levels while also confirming that all environmental standards and laws are met. The model has an excellent match with the CORMIX output.

D. V. Salgueiro et all (2015) [22] The thermal effluent dispersion from a power plant in Portugal, which collects water for cooling and subsequently discharges it at a 10 ºC temperature increase, was studied using the (MOHID) 3D hydrodynamic model. During August and October of 2013, a simulation was run with north and south winds as shown in figs 5,6. The results showed that temperature increase is decay from 10 ºC near the outlet to 2 ºC at 2 km away from the outlet.

Wind direction and tide play a substantial effect on plume dispersion, according to model simulations. Under north wind dominance, a well-mixed plume is visible, as contrast to a limited wider plume under south wind conditions that can led to more efficiency losses for the power plant operation, since the water at the intake is continuously warming.

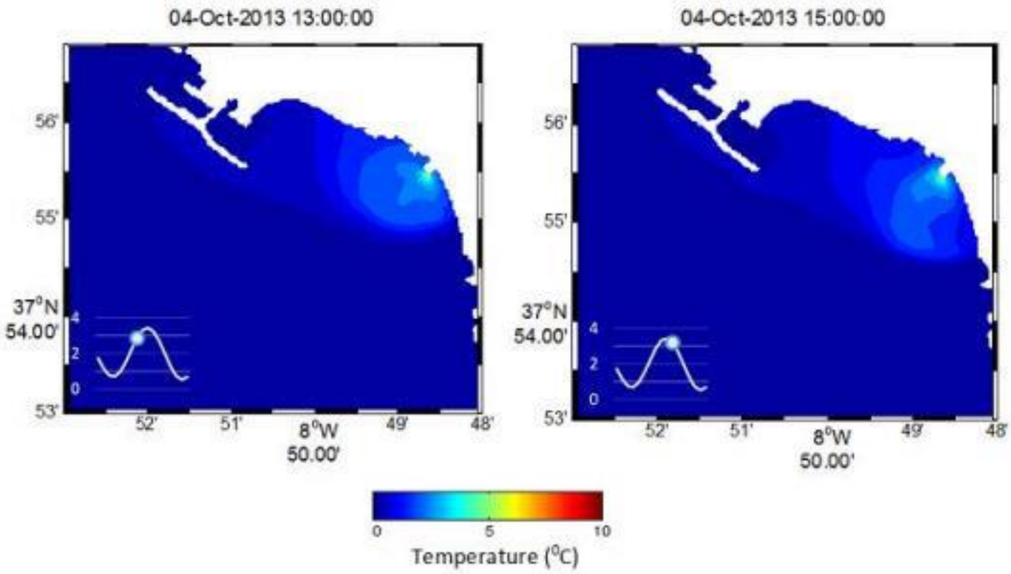


Fig 5. Sea surface temperature profile for cooling water discharge in coastal area, subjected to south wind scenarios.

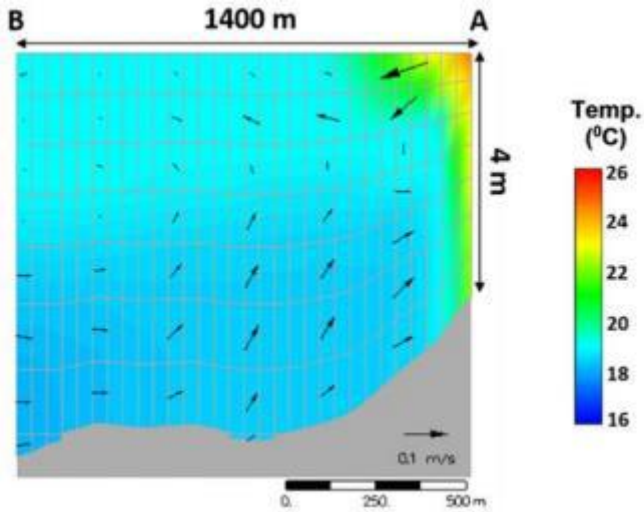


Fig 6. Sea surface temperature profile for cooling water discharge in coastal area, subjected to north wind scenarios.

Ahmad Rezaee Mazyak et al. (2018) [23] Made a simulation by CORMIX model as shown in fig 7 to the outfall pipeline of SAKO desalination plant in the persian gulf Iran which has daily productivity of one million m3/d. The excess salinity in a 200-meter radius around the outfall should be less than 10% of the ambient salinity, according to the environmental regulation. According to near-field model results, the salinity increase at 18 metres from the outfall will be roughly 4.17 PSU, which is less than 10% of the ambient salinity as shown in fig 8. As a result, the environmental criteria are fully met.

Mazen Abualtayef et al. (2019) [24] Used the CORMIX v 9.0 to made a numerical simulation to the brine effluent outfall of Deir Al-Balah desalination plant to study the dilution and dispersion behavior of effluent brine through eight disposal systems such as: single port outfall, alternating multi-port diffuser, unidirectional multi-port diffuser and staged multi-port diffuser. The simulation results for various outfalls configurations show that the fanned-out unidirectional multi-port outfall is the optimal design configuration, that can meet the disposal standard in the worst ambient condition at the edge of mixing zone to less than 1.25% above seawater salinity as shown in figs 9,10,11.

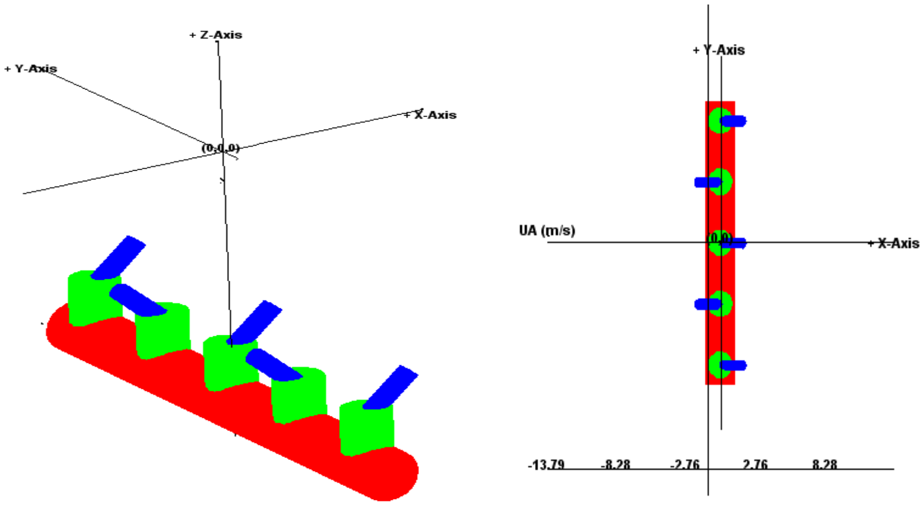


Fig 7. Arrangement of multiport diffuser.

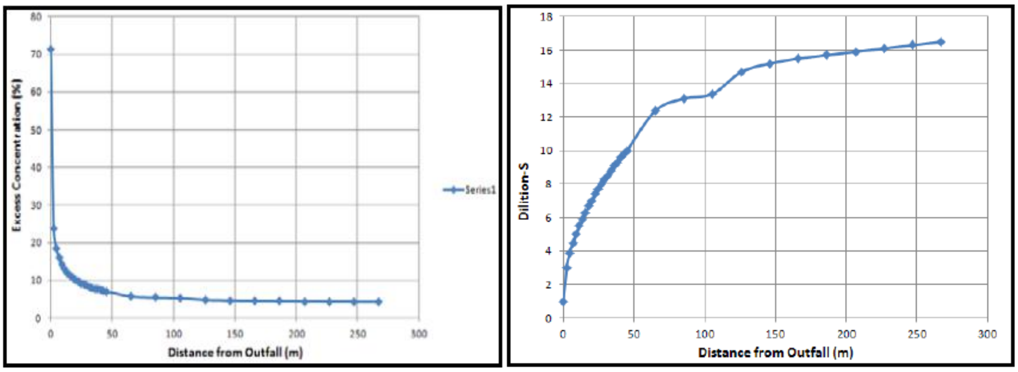


Fig 8. Concentration and dilution variation along the plume centerline.

KATTEB A et al. (2019) [25] Conducted a numerical study for the dilution and dispersion of fouka desalination plant brine effluent marine outfall using CORMIX for near-field area, Delft-3D is used for the far-field mixing area, the results showed that if input data are of high quality to the CORMIX model, it becomes a powerful and reliable management tool for the brine effluent environmental impacts assessment as shown in figs 12 to 15.

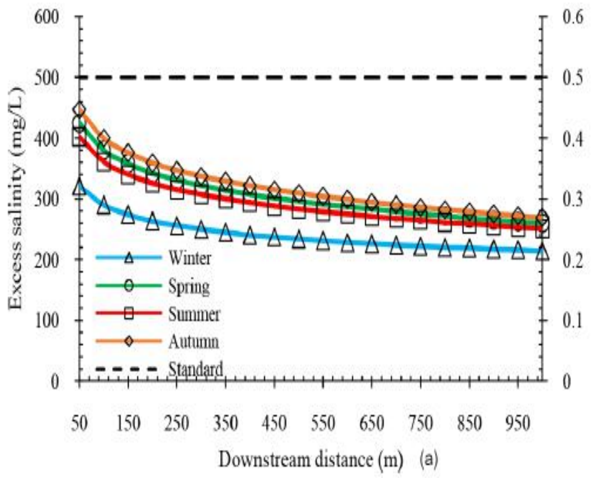


Fig 9. Excess salinity with downstream distance results at RMZ

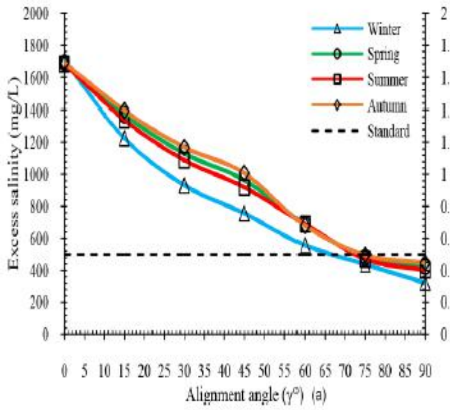


Fig 10. Brine dilution as a function of diffuser alignment angle

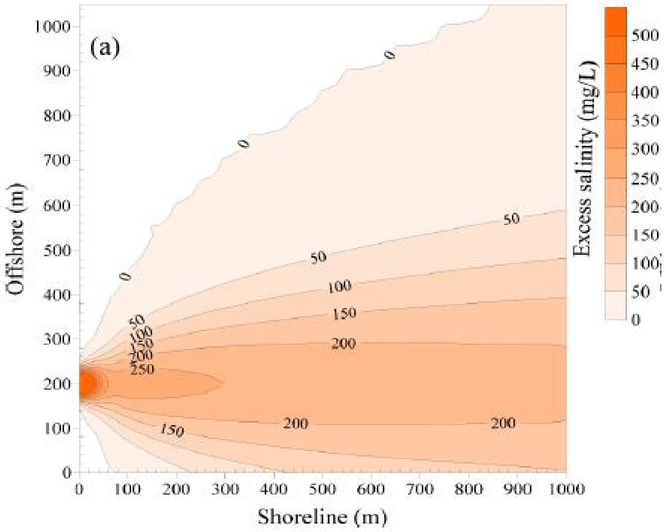


Fig.11. Plume dispersion away from shore line.

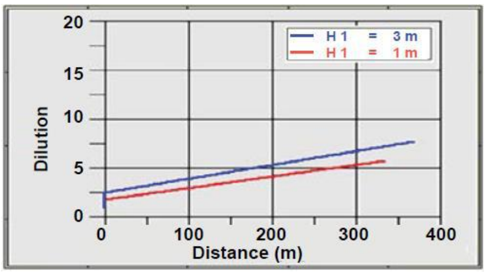


Fig. 12 Dilutions related to different Outfall depth.

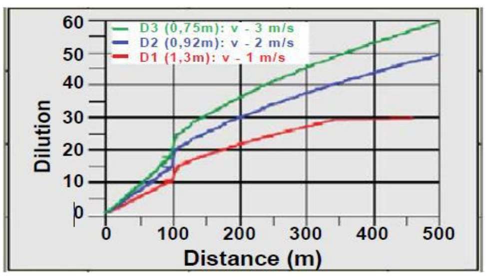


Fig.13 Dilutions with different diameters of diffuser.

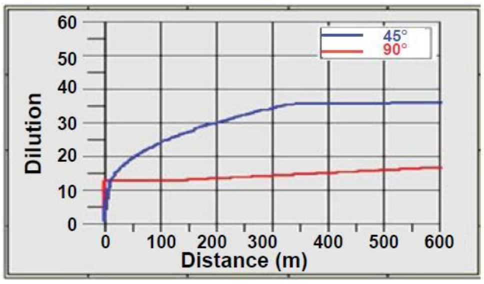


Fig.14 Dilutions related to different Inclination angles.

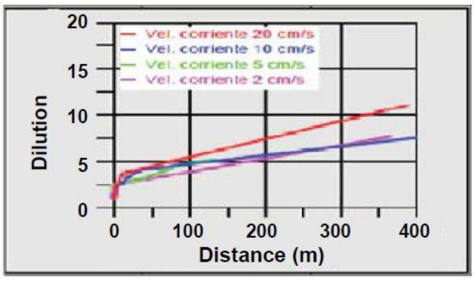


Fig.15 Dilutions according to diffuser different environmental speed values.

Jabel A. Ramirez Naranjo, et al. (2019) [26] Comparative analysis between a venturi-type diffuser and several alternate diffuser installations with CFD simulations have been conducted. Venturi diffusers are currently one of the best existing technologies to reduce the environmental impact of brine in marine environments near discharge points in desalination plants, protecting benthic ecosystems in this way. The CFD is a very valuable computational tool since it allows to simulate the approximate behavior of a fluid in many different conditions, obtaining much information with great ease, and with very reduced costs.

A computational model of this initial design was built and validated with empirical data from the prototypes installed. Subsequently, other state of the art diffuser technologies was simulated with CFD in order to perform a comparative analysis of results. Mixing capacity, effluent dynamics, temperature gradients, density, salinity and dilution were studied.

Preliminary results point to an improvement in the effluent dilution. The use of venturi diffusers in the discharge nozzle causes a change in the behavior of the plume that improves the mixing and dilution processes, compared to the technological alternatives. All of this resulting in environmental benefit.

The physical processes characterizing venturi technology give rise to a typology of effluent plume different and more efficient to those of conventional methods.

III. CONCLUSIONS

The study until now was performed on analyzing and predicting the behavior and the performance of the brine effluent dilution and dispersion. Many researchers conducted a numerical simulation using hydrodynamic models and made a physical model to the outfalls to reach the best dilution and many more. Some questions regarding the outfall length, diameter, the best number of diffuser ports, and design requirements need to exactly solved. The unified design approach of the marine outfall has not achieved yet.

REFERENCES

[1] J.V. Del Benel et all, Ocean brine disposal. Desalination9, 7 (1994) 365-372.

[2] Vlado Malacic (2001) Numerical modelling of the initial spread of sewage from diffusers in the Bay of Piran (northern Adriatic) ecol model 138- 173–191.

[3] Merih Ozcan, Dr. K. Tunc Gokce, Numerical Model (MIKE21) Applications in Outfall Design: Case Study from Turkey. MWWD 2002.

[4] Thomas Hoepner*, Sabine Lattemann (2002), Chemical impacts from seawater desalination plants - a case study of the northern Red Sea. Desalination 152 (2002) 133-140.

[5] Anton Purnama et all, Modeling dispersion of brine waste discharges from a coastal desalination plant. Desalination 15x (2003) 000–000.

[6] Fernández-Torquemada, Y., Sáanchez-Lizaso, J. L., & González- Correa, J. M. 2005. Preliminary results of the monitoring of the brine discharge produced by the SWRO desalination plant of Alicante (SE Spain). Desalination, 182, 395–402.

[7] A.M.O. Mohamed et all (2005), Impact of land disposal of reject brine from desalination plants on soil and groundwater. Desalination 182 (2005) 411–433.

[8] Alameddine, I. and El-Fadel, M. (2007). "Brine Discharge from Desalination Plants: A modeling Approach to an Optimized Outfall design." Desalination, 214: 241-260.

[9] Haibo Niu, et al. Validation of A Buoyant Jet Model (Promise) Against Laboratory Data. 2006.

[10] H.H. Al-Barwani*, Anton Purnama (2007), Evaluating the Effect of Producing Desalinated Seawater on Hypersaline Arabian Gulf. European Journal of Scientific Research 22 No.2 (2008), pp.279-285.

[11] Kikkert, G.A., Davidson, M. J., Nokes, R. I. (2007). Inclined negatively buoyant discharges. J. Hydraulic Eng. 133(5), 545- 554.

[12] Blue Hill Hydraulics Incorporated (2007) Thermal Mixing Zone Analysis and Dilution Study Chesapeake Bay at Calvert Cliffs Nuclear Power Plant, Maryland.

[13] Esperanca Gacia et all (2007), Impact of the brine from a desalination plant on a shallow seagrass (Posidonia Oceanica) meadow Estuarine. Estuarine coastal and shelf scince 72(4):579-590.

[14] Jochen Kämpf, Impacts of blending on dilution of negatively buoyant brine discharge in a shallow tidal sea. Marine Pollution Bulletin 58 (2009) 1032–1038.

[15] A. Etemad-Shahidi, et al. An alternative data driven approach for prediction of thermal discharge initial dilution using tee diffusers. Int. J. Environ. Sci. Tech., 7 (1), 29-36, Winter 2010.

[16] P. Palomar et al. (2012). Near field brine discharge modelling part 1: Analysis of commercial tools Desalination 290 (2012) 14–27.

[17] Hesham El-Badry et al. [42] Hydrodynamic Modeling of the Gulf of Aqaba. Journal of Environmental Protection, 2012, 3, 922-934.

[18] Candela Marco-Méndez, et al. Comparing four mixing zone models with brine discharge measurements from a reverse osmosis desalination plant in Spain. Desalination 286 (2012) 217–224.

[19] Yasser Shawky et all, Environmental and hydraulic design of thermal power plants outfalls ''Case study: Banha Thermal Power Plant, Egypt'' Ain Shams Engineering Journal (2012) 4, 333–342.

[20] Carlos Palacio, et al. Simulation of Near Field Dilution of The Submarine Outfall of Santa Marta (Colombia). Dyna rev.fac.nac.minas vol.80 no.182 Medellín Nov./Dec. 2013.

[21] Sami Maalouf et all, Planning and Design of Desalination Plants Effluent Systems. Desalination 333 (2014) 134–145.

[22] D. V. Salgueiro et all, Modelling the thermal effluent of a near coast power plant (Sines, Portugal). Journal of Integrated Coastal Zone Management, 15(4):533-544 (2015).

[23] Ahmad Rezaee Mazyak et al. (2018) Numerical Simulation of Near Field and Far Field Brine Discharge from Desalination Plants (A Case Study in Persian Gulf). International Journal of Systems Applications, Engineering & Development.

[24] Mazen Abualtayef et al. (2019). Desalination of seawater in the Gaza Strip: the regional short-term low-volume (STLV) seawater desalination plant of Deir Al-Balah as a case study. dwt.2019.23425.

[25] Katteb A et al. (2019) Modelling and Design of Brine Outfall Discharges: Case of A desalination Plant in Mediterranean. Jr. of Industrial Pollution Control 34(1) 1862-1871.

[26] Jabel A. Ramirez Naranjo, et al. Analysis of the Performance of Different Brine Diffuser Technologies with CFD Software. IDAWC 2019.