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Client : IVRCL Infrastructures & Projects Limited, Chennai
Project Title : Mathematical modelling study on the dispersion of brine reject from CWDL desalination plant at Minjur.
Project No. : IND-141-0506
Abstract :

Chennai Metropolitan Water Supply & Sewerage Board (CMWSSB) has planned to augment the water supply to Chennai city by setting up a 100 MLD Seawater Desalination Plant at Minjur, north of Chennai on Design, Build, Own, Operate and Transfer (DBOOT) basis. The project has been awarded to Special Purpose Vehicle (SPV) named as Chennai Water Desalination Limited (CWDL) .

The oceanographic investigations were carried out by Indomer Coastal Hydraulics (P) Ltd., Chennai in five parts viz., Part I: Marine EIA studies, Part II: Delineation of LTL/HTL and CRZ, Part III: Marine Geophysical investigations, Part IV: Mathematical modelling study on the dispersion of brine reject disposed in the sea and Part V: Water quality. Separate reports have been submitted under each part. This report comprising the Part IV investigations, presents exclusively the results of the mathematical modelling studies on the dispersion and mixing of the brine reject disposed in the sea.

References : IVRCL/CWDL/MH/001/05-6

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EXECUTIVE SUMMARY

Chennai Metropolitan Water Supply & Sewerage Board (CMWSSB) has planned to augment the water supply to Chennai city by setting up a 100 MLD Seawater Desalination Plant at Minjur, north of Chennai on Design, Build, Own, Operate and Transfer (DBOOT) basis. The project has been awarded to Special Purpose Vehicle (SPV) named as Chennai Water Desalination Limited (CWDL) consisting of IVRCL Infrastructures & Projects Ltd., Chennai and BEFESA Construccion y Tecnologia Ambiental, S.A., Spain under twenty five years DBOOT scheme.

Indomer Coastal Hydraulics (P) Ltd, Chennai, has carried out various oceanographic investigations in connection with seawater intake and brine reject outfall. The reports were prepared in five parts viz., Part I: Marine EIA studies, Part II: Delineation of LTL/HTL and CRZ, Part III: Marine Geophysical investigations, Part IV: Mathematical modelling study on the dispersion of brine reject disposed in the sea and Part V: Water quality. The findings of the mathematical modelling studies on the dispersion and mixing of the brine reject disposed in the sea has been presented in this report.

The Land Fall Point (LFP) of the water intake pipe line will be located approximately at Latitude 13°18′53″ N and Longitude 80°20′50″ E (Everest 1830). The volume of the seawater intake to the desalination plant is 237 MLD (10,000 m^3/hour) and the brine reject discharge is 137 MLD (5710 m^3/hour). The salinity of the brine reject at the outfall point is 70 ppt. The available literature and the measurement shows that the ambient salinity in the project region exists around 35 ppt.

The inland region of the project area is a plain and barren land with thorny bushes and sparse wild vegetation. On the eastern side of the area, there is a long and nearly straight coastline that is exposed to an open sea, the Bay of Bengal. The morphology of this region is influenced by three climatic conditions, viz., southwest monsoon (June – September), northeast monsoon (Mid October to Mid March) and fair weather period from April to May. The tides in this region are semi diurnal with mean spring tidal range of 1.01 m and neap tidal range of 0.41 m.

The tide and wind induced flow field over the project area is determined using the flow module of the Delft3D package of WL | Delft Hydraulics. The Delft3D modelling studies were conducted at INDOMER in technical collaboration with Alkyon Hydraulic Consultancy & Research, The Netherlands.

The flow fields were simulated over the project region with three open ocean boundaries namely (i) an 'overall model' covering the entire Bay of Bengal (BoB model), (ii) an 'area model' covering the area between Cuddalore and Nellore and (iii) a highly detailed 'site model at the designated project location. The depth values for an individual point are determined by an interpolation program using the digitized bathymetry from the field survey and from the nautical charts. The simulations were done for no wind conditions and strong wind conditions corresponding to NE monsoon and SW monsoon. In each case, the currents were simulated for spring and neap tidal days. Further, on each tidal days, the flow corresponding to flood and ebb tidal phases were *simulated. In total 12 cases (3 winds X 2 tides X 2 tidal phases) were simulated. These simulations were repeated for the three typical outfall locations viz., 500 m, 1000 m and 2000 m distance from the shoreline into the sea.*

The flow field and the dispersion of the brine reject for outfall point at 500 m from coast off Minjur for three different wind conditions namely no wind, extreme NE wind and extreme SW wind for flood and ebb phases of the spring and neap tide were evaluated. The results show that the current speed around the outfall location is generally weak (5 cm/s) for no wind condition. For strong wind during NE monsoon and SW monsoon the currents generally prevailed around 15 cm/s and 35 cm/s respectively.

It is also observed that the concentration of salinity in the vicinity of the outfall discharge point reduced rapidly from 70 ppt to 35.1 ppt with in 500 m under no wind condition. The model shows a rapid dispersion of the brine around the discharge point within 500 m radius. The distribution of dissolved salinity of the brine reject is nearly symmetrical from the outfall on either side of the coastline. Under the strong wind conditions during NE monsoon and SW monsoon, the wind field dominates the current in the coastal region off Minjur. With the influence of the tide and wind induced currents in this region, the brine reject coming out of the diffuser, travel along the coast towards south during NE monsoon and the towards north during SW monsoon. The salinity of the reject gets diluted from 70 ppt to 35.1 ppt within 100 m distance from the outfall diffuser.

The mixing of the brine reject for no wind condition for the outfall located at 1000 m distance and 2000 m distance offshore are also presented. Under the strong wind conditions during NE monsoon and SW monsoon, the dispersion pattern is similar to brine reject at 500 m distance from the coast. The salinity of the reject gets diluted from 70 ppt to 35.1 ppt within 100 m distance from the outfall.

The proposed brine reject does not contain any toxic or organic pollutant. From the results it is observed that even during the calm sea, the salinity of the brine reject discharged at outfall point gets diluted to nearly ambient value of 35.1 ppt within a distance of 500 m. Such dilution would help to keep the seawater environment within the acceptable limit from the environmental point of view.

Based on the study, it is suggested to keep the outfall with designed diffuser port arrangements anywhere with a minimum distance of 500 m into the sea. Based on the dispersion pattern, it is preferred that a minimum of 1000 m distance between the outfall diffuser and intake head may be maintained in order to avoid the disposed reject re-entering into the intake before appropriate dilution. The outfall may be located on the northern side of the intake as the flow remains northwards for eight months in a year. Outfall may be placed closer to the shore than the intake as the turbulence inducing the mixing would be the maximum at nearshore due to the presence of: surf zone, longshore currents, strong orbital currents induced due to shoaling waves, relatively stronger tidal currents, currents due to wave set up etc. Further, placing the intake farther inside the sea than the outfall will help in obtaining relatively clean water.

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1. INTRODUCTION

Chennai Metropolitan Water Supply & Sewerage Board (CMWSSB) has planned to augment the water supply to Chennai city by setting up a 100 MLD Seawater Desalination Plant at Minjur, north of Chennai on Design, Build, Own, Operate and Transfer (DBOOT) basis. The project location is shown in Fig. 1 and the satellite imagery of the project region is shown in Fig. 2. The project has been awarded to Special Purpose Vehicle (SPV) named as Chennai Water Desalination Limited (CWDL) consisting of IVRCL Infrastructures & Projects Ltd., Chennai and BEFESA Construccion y Tecnologia Ambiental, S.A., Spain under twenty five years DBOOT scheme.

The CWDL has requested Indomer Coastal Hydraulics (P) Ltd, Chennai, to carry out various oceanographic investigations in connection with seawater intake and brine reject outfall. The oceanographic investigations were carried out in five parts viz., Part I: Marine EIA studies, Part II: Delineation of LTL/HTL and CRZ, Part III: Marine Geophysical investigations, Part IV: Mathematical modelling study on the dispersion of brine reject disposed in the sea and Part V: Water quality. Separate reports have been submitted under each part. This report comprising of Part IV investigations, presents exclusively the results of the mathematical modelling studies on the dispersion and mixing of the brine reject disposed in the sea.

2. SCOPE

i) *to conduct the mathematical modelling study using Delft3D hydrodynamic models in order to simulate the mixing pattern of the brine reject discharged into the sea and its behaviour at the intake location, and*

ii) *to prepare a report to meet the requirements of MoEF.*

3. METHODOLOGY

Flow-Dispersion model

Conventions and Definitions

Units: Units of all parameters and variables in the model study are according to international SI conventions. *Coordinate system:* The coordinate system used for model grid generation and other horizontal positioning was UTM, based on the Everest 1830 spheroid, with a central meridian of 81° E, zone 44. *Vertical reference level:* The depth information used in the tidal flow models is relative to Mean Sea Level (MSL); depths below MSL are defined positive. *Bottom Depths*: For the schematisation of depths in the model, the depths of the sea floor were taken from the Naval Hydrographic Charts for the larger region and the measured bathymetry was taken for the project region.

Directions:

Flow: Flow directions refer to the direction towards which the flow is taking place. Directions of the flow are always given clockwise w.r.t. North. The Unit is degrees, where 360 degrees cover the circle. *Wind*: Wind directions refer to the direction from which the wind is approaching. Directions of the wind are always given clockwise w. r. t. North. The Unit is degrees, where 360 degrees cover the circle.

The tide and wind induced flow field over the project area is determined using the flow module of the *Delft3D* package of WL|Delft Hydraulics.

The Delft3D modelling studies are being conducted at INDOMER in technical collaboration with Alkyon Hydraulic Consultancy & Research, The Netherlands.

Delft3D-Flow module is a multi-dimensional (2D or 3D) hydrodynamic flow simulation model, which solves shallow-water equations for given boundary conditions to compute non-steady flow field induced by tidal and meteorological forcing, using an implicit finite difference method (ADI) on a staggered spherical or curvilinear orthogonal grids. The basic equations in the curvilinear orthogonal system used in Delft3D-flow module are given below:

Continuity equation:

$$\frac{\partial \zeta}{\partial t}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\left[(d+\zeta)U\sqrt{G_{\eta\eta}}\right]}{\partial \xi}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\left[(d+\zeta)V\sqrt{G_{\xi\xi}}\right]}{\partial \eta}=Q$$

Momentum equations in ξ- and η- directions:

$$\frac{\partial u}{\partial t}+\frac{u}{\sqrt{G_{\xi\xi}}}\frac{\partial u}{\partial \xi}+\frac{v}{\sqrt{G_{\eta\eta}}}\frac{\partial u}{\partial \eta}+\frac{\omega}{d+\zeta}\frac{\partial u}{\partial \sigma}+\frac{uv}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\xi\xi}}}{\partial \eta}+$$

$$-\frac{v^2}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\eta\eta}}}{\partial \xi}-fv=-\frac{1}{\rho_0\sqrt{G_{\xi\xi}}}P_\xi+F_\xi+$$

$$+\frac{1}{(d+\zeta)^2}\frac{\partial}{\partial \sigma}\left(\nu_V\frac{\partial u}{\partial \sigma}\right)+M_\xi$$

$$\frac{\partial v}{\partial t}+\frac{u}{\sqrt{G_{\xi\xi}}}\frac{\partial v}{\partial \xi}+\frac{v}{\sqrt{G_{\eta\eta}}}\frac{\partial v}{\partial \eta}+\frac{\omega}{d+\zeta}\frac{\partial v}{\partial \sigma}+\frac{uv}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\eta\eta}}}{\partial \xi}+$$

$$-\frac{u^2}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\sqrt{G_{\xi\xi}}}{\partial \eta}+fu=-\frac{1}{\rho_0\sqrt{G_{\eta\eta}}}P_\eta+F_\eta+$$

$$+\frac{1}{(d+\zeta)^2}\frac{\partial}{\partial \sigma}\left(\nu_V\frac{\partial v}{\partial \sigma}\right)+M_\eta$$

Vertical velocity ω in the sigma co-ordinate system is computed from the equation:

$$\frac{\partial \zeta}{\partial t}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\left[(d+\zeta)u\sqrt{G_{\eta\eta}}\right]}{\partial \xi}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}\frac{\partial\left[(d+\zeta)v\sqrt{G_{\xi\xi}}\right]}{\partial \eta}+\frac{\partial \omega}{\partial \sigma}=H\left(q_{in}-q_{out}\right)$$

Model Setup

In the present study, the flow field was simulated over the project region with three open ocean boundaries. As the water depths in the project area is less than 20 m, the fluid medium is assumed homogeneous and the 2-D flow field in the project area forced by the astronomical tide and atmospheric wind is simulated. A series of three nested grids are used to generate the open boundary conditions for the simulation of the flow field over the project area, namely (i) an *'overall model'* covering the entire Bay of Bengal (BoB model), (ii) an *'area model'* covering the area between Cuddalore and Nellore and (iii) a highly detailed *'site model* at the designated project location.

The *overall model* of the Bay of Bengal generates a consistent set of boundary conditions for the *area model*, which in turn generates the boundary conditions for the detailed *'site model.*

Grid Generation

The first step in the numerical simulation of flow model begins with the specification of the open and the closed boundaries of the models. The next step in the schematisation process is the design and generation of the computational grid. For the design of a spherical grid the following items are important: i) The dimensions of an individual cell and ii) the total number of computational points.

For the design of a curvilinear grid the following items are important: i) theorthogonality of the individual cells (only for curvilinear grids), ii) the spatial variation of the dimensions of the cells and iii) the areas in which the grid has to be refined.

The ultimate computational grid is a compromise between the above items and also the selected dimensions of the model and the position of the boundaries

For the overall model of the Bay of Bengal a spherical grid system was used. On the other hand for the area model and detailed site model, curvilinear grid system was used. The *Bay of Bengal model* covers the area between 70°E and 100°E and between 0°N and 22.5°N and represents an area of approximately 3000 km x 2400 km (Fig. 3). The *selected grid* size of the spherical grid is 3.0 geographical minutes in both directions (i.e. 0.05 geographical degrees). The grid comprises approximately 1,86,537 active computational points.

The Bay of Bengal model, which generates the boundary conditions for the area models, is forced by 23 astronomical components at the model boundary. The model has been calibrated using predicted and observed water levels at various locations along the coast of India, Bangladesh, Myanmar, Thailand and Sri Lanka.

For the *area model*, the offshore area bounded between Nellore and

Cuddalore was considered. The grid size in this curvilinear grid system was chosen varying from 1200 m at offshore to 450 m at nearshore region (Fig. 4). The grid comprises of 200 x 100 = 20,000 points, with approximately 18,000 active computational points.

In the *detailed model,* curvilinear grid was used at the project region. The offshore boundary of the model is located near the 80 m depth contour (Fig. 5). The generated computational grid comprises 260 x 200 = 52,000 points, with approximately 40,000 active computational points. The dimension of an individual cell ranges from 50 m to 75 m in the nearshore, and 250 m x 400 m near offshore boundary.

Boundary conditions

The Bay of Bengal model is forced by the tidal water level variations along the open sea boundaries. For generation of these boundary conditions, the Topex/Poseidon database was used. The boundary conditions are represented using 16 short-period tidal constituents (Q1, O1, M1, P1, K1, J1, OO1, 2N2, MU2, N2, NU2, M2, L2, T2, S2 and K2) and seven long-period tidal constituents (MTM, MF, MSF, MM, MSM, SSA and SA) according to:

$$h_t = A_0 + \sum_{i=1}^{n} f_i A_i \cos(\omega_i t + (v_0 + u)_i - g_i)$$

with:

h_t = water level at time = t
A_o = mean value of the signal
A_i = amplitude of component i
f_i = nodal amplitude factor of component i
ω_i = angular frequency of component i
$(v_0+u)_i$ = astronomic argument of component i
g_i = phase lag of component i

The boundary conditions for the *area model* and the *detailed site model* around the project location are prescribed as time series of tidal water level variations along the open boundaries of the model. Moreover, applying boundary conditions described by water levels will enable us to model wind-driven currents, as they will not be obstructed by this type of model boundaries.

Depth Schematization

As a result of the grid generation, the coordinates for each computational point become available. The depth values for an individual point are determined by an interpolation program using the digitized bathymetry from the field survey and from the nautical charts.

4. RESULTS

4.1. Baseline environment

The Desalination plant is proposed to be set up about 4 km north of Ennore Port, which is 22 km north of Chennai (Fig. 1). The project site lies in Kattuppalli village, Minjur, between the Buckingham canal and the Bay of Bengal. The Land Fall Point (LFP) of the water intake pipe line will be located approximately at Latitude 13° 18′53″ N and Longitude 80° 20′50″ E (Everest 1830). The *Pulicat lake,* second largest brackish water lake in India, lies north of the project area, with its mouth located about 15 km north of this region. The inland region of the project area is a plain and barren land with thorny bushes and sparse wild vegetation. On the eastern side of the area, we have a long and nearly straight coastline that is exposed to an open sea, the Bay of Bengal. This coastal region comprises of fairly wide beaches with well-defined foreshore and elevated backshore. The morphology of this region is influenced by the 3 climatic conditions, viz., southwest monsoon (June – September), northeast monsoon (Mid October to Mid March) and fair weather period from April to May. Unlike the northern part of the east coast of India, this part of the coast is influenced more by the northeast monsoon weather conditions than those during the other two seasons. The nearshore remains relatively steeper due to the action of high waves during monsoon seasons. The seabed in nearshore primarily comprises of sand without any complex bathymetric features. Sand banks are observed offshore and northeast of this coastal region, which perhaps have been formed over the geological period from sediments transported through the Ennore creek and the Pulicat Lake. The newly constructed Ennore Port breakwaters also influence the littoral drift in this region in recent years.

The tides in this region are semi diurnal with mean spring tidal range of 1.01 m and neap tidal range of 0.41 m. The significant wave heights vary between 0.5 and 1 m during February to April, 1 and 2.5 m during May to September and between 1 and 2 m during the rest of the year. The tidal effects on currents in the nearshore region are small and the currents are dominated by wind. By the onset of southwest monsoon, the coastal currents turn northward gradually. Southward transport occurs during northeast monsoon.

The available literature shows that the ambient salinity in the project region exists around 35 ppt. The vertical salinity gradient is not relevant in shallow coastal waters off Minjur and also no appreciable density stratification can be expected in this region.

The volume of the seawater intake to the desalination plant is 237 MLD (10,000 m^3/hour) and the brine reject discharge is 137 MLD (5710 m^3/hour). The salinity of the brine reject at the outfall point is 70 ppt.

4.2. Flow-Dispersion model

The tide and wind induced flow and the subsequent advection – diffusion in the sea off the project region are determined using the Delft3D-Flow module. Three nested grids are used to simulate the tide and wind induced flow and the dispersion of the brine reject discharged into the sea. The bathymetry used in the BoB, intermediate and the detailed models are shown in Figs. 6 to 8.

Using the *Delft 3D flow* model, various flow fields induced by tide in combination of wind have been simulated for intermediate model, and detailed model off Minjur. The simulations were done for no wind conditions and strong wind conditions corresponding to NE monsoon and SW monsoon. In each case, the currents were simulated for spring and neap tidal days. Further, on each tidal days, the flow corresponding to flood and ebb tidal phases were simulated. In total 12 cases (3 winds X 2 tides X 2 tidal phases) were simulated.

These simulations were repeated for the three typical outfall locations viz., 500 m, 1000 m and 2000 m distance from the shoreline into the sea.

4.3. Calibration

Delft3D-flow simulations for the BoB (Bay of Bengal) model were compared with predicted tides at Chennai and Visakhapatnam as presented in Indian Tide Table. The comparison is shown in Fig. 9 and a good agreement between the simulated results and the predicted tides is noticed for the BoB model. It was also compared with the measured tides at Chennai Fishing harbour.

4.4. Dispersion

The characteristics of the brine reject used in the dispersion study are: (i) the salinity value of the brine reject at the point of outfall is 70 ppt, (ii) the rate of discharge is 5710 m^3/hr (1370 MLD). The ambient salinity of the seawater considered for this region is 35 ppt.

The results on flow simulation and the dispersion of brine reject from the outfall without wind, which defines the worst scenario of mixing (as the dispersion will be minimum in the absence of wind) are presented. Also the flow field and the dispersion of brine reject under extreme wind condition i.e., 10 m/s (36 km/hour), i.e., corresponding to 25% exceedence during NE and SW monsoons periods are presented.

Outfall at 500 m distance into the sea

No wind Condition: The tide induced flow field for the no wind condition during the flood and ebb phases on the spring tidal day are shown in Figs. 10 and 11. The mixing of the brine reject under these flow conditions are shown in Figs. 12 and 13. The tide induced flow field without the influence of wind (i.e. for no wind condition) during the flood and ebb phases on the neap tidal day are shown in Figs. 14 and 15. The mixing of the brine reject under these flow conditions are shown in Figs. 16 and 17.

NE monsoon – Strong wind condition: The tide induced flow field for the strong wind condition in NE monsoon during the flood and ebb phases on the spring tidal day are shown in Figs. 18 and 19. The mixing of the brine reject under these flow conditions are shown in Figs. 20 and 21. The tide induced flow field for the strong wind condition in NE monsoon during the flood and ebb phases on the neap tidal day are shown in Figs. 22 and 23. The mixing of the brine reject under these flow conditions are shown in Figs. 24 and 25.

SW monsoon – Strong wind condition: The tide induced flow field for the strong wind condition in SW monsoon during the flood and ebb phases on the spring tidal day are shown in Figs. 26 and 27. The mixing of the brine reject under these flow conditions are shown in Figs. 28 and 29. The tide induced flow field for the strong wind condition in SW monsoon during the flood and ebb phases on the neap tidal day are shown in Figs. 30 and 31. The mixing of the brine reject under these flow conditions are shown in Figs. 32 and 33.

The flow field and the dispersion of the brine reject for outfall point at 500 m from coast off Minjur (i.e. at 6m depth of water) for three different wind conditions namely no wind, extreme NE wind and extreme SW wind for flood and ebb phases of the spring and neap tide are presented. The results show that the current speed around the outfall location is generally weak for no wind condition. For strong wind during NE monsoon and SW monsoon the currents generally prevailed around 15 cm/s and 35 cm/s respectively.

It is also observed that the concentration of salinity in the vicinity of the outfall discharge point reduced rapidly from 70 ppt to 35.1 ppt with in 500 m under no wind condition. The model shows a rapid dispersion of the brine around the discharge point within 500 m radius, which is on the otherhand normally expected. The distribution of dissolved salinity of the brine reject is nearly symmetrical from the outfall on either side of the coastline. But, a small deviation towards southeastern direction is seen at water depths beyond 15m due to the presence of offshore submerged shoal.

Under the strong wind conditions during NE monsoon and SW monsoon, the wind field dominates the current in the coastal region off Minjur. With the influence of the tide and wind induced currents in this region, the brine reject coming out of the diffuser, travel along the coast towards south during NE monsoon and the towards north during SW monsoon. The salinity of the reject gets diluted from 70 ppt to 35.1 ppt within 100 m distance from the outfall diffuser.

The tide and wind induced flow fields during different seasons would remain the same for the cases of outfall located at 1000 m distance and 2000 m distance from the coastline into sea.

Outfall at 1000 m distance into the sea

The mixing of the brine reject for no wind condition (worst scenario) during the flood and ebb phases on the spring tidal day are shown in Figs. 34 and 35. The mixing of the brine reject during the flood and ebb phases on the neap tidal day are shown in Figs. 36 and 37. It is also observed that the concentration of salinity in the vicinity of the outfall point reduced rapidly from 70 ppt to 35.1 ppt with in 500 m distance under no wind condition. The model shows a rapid dispersion of the reject around the discharge point within 500 m radius. Under the strong wind conditions during NE monsoon and SW monsoon, the dispersion pattern is similar to brine reject at 500 m distance from the coast (Figs. 20, 21, 24, 25, 28, 29, 32, and 33). The salinity of the reject gets diluted from 70 ppt to 35.1 ppt within 100 m distance from the outfall.

Outfall at 2000 m distance into the sea

The mixing of the brine reject for no wind condition (worst scenario) during the flood and ebb phases on the spring tidal day are shown in Figs. 38 and 39. The mixing of the brine reject during the flood and ebb phases on the neap tidal day are shown in Figs. 40 and 41. Once again, it is also observed that the concentration of salinity in the vicinity of the outfall point reduced rapidly from 70 ppt to 35.1 ppt with in 500 m distance under no wind condition. The model shows a rapid dispersion of the reject around the discharge point within 500 m radius.

Under the strong wind conditions during NE monsoon and SW monsoon, the dispersion pattern is similar to brine reject in to sea at 500 m distance from the coast (Figs. 20, 21, 24, 25, 28, 29, 32, and 33). The salinity of the reject gets diluted from 70 ppt to 35.1 ppt within 100 m distance from the outfall.

5. DISCUSSION AND CONCLUSIONS

The mathematical modelling studies were carried out to understand the dispersion characteristics of the brine reject for typical cases of location of the outfall at 500 m, 1000 m and 2000 m distance into the sea.

The simulation shows that the tide induced flow with absences of wind in this region is small of the order of 5 cm/s. During monsoon months, the wind induced current dominates the currents in this region. The combination of tide and wind induced flow velocity of the order of 15 cm/s and 35 cm/s were observed during NE monsoon and SW monsoon respectively.

When there is no wind, the salinity of the brine reject reduces from 70 ppt to 35.1 ppt (near to ambient salinity which is assumed as 35 ppt) within 500 m radius from the outfall, whereas during monsoon, it gets diluted to 35.1 ppt within 100 m radius from the outfall. Similar results were noticed for the outfall located at 1000 m distance and 2000 m distance into the sea.

The proposed brine reject does not contain any toxic or organic pollutant. The higher salinity of the brine reject is the main source of pollutant discharged into sea. The actual environmental aspect is the dilution of the higher saline water in the near shore waters. From the results it is observed that even during the calm sea, the salinity of the brine reject discharged at outfall point gets diluted to nearly ambient value of 35.1 ppt within a distance of 500 m. Such dilution would help to keep the seawater environment within the acceptable limit from the environmental point of view.

The coastline off Minjur is a sandy beach with no direct proximity to any sensitive area such as mangroves, coral reefs or fish spawning ground within five kms form the project site. The brine reject from the desalination plant discharged at proper distance off the coast will have negligible impact on the marine environment.

Based on the present study, it is suggested to keep the outfall with designed diffuser port arrangements anywhere with a minimum distance of 500 m into the sea. Based on the dispersion pattern, it is preferred that a minimum of 1000 m distance between the outfall diffuser and intake head may be maintained in order to avoid the disposed reject re-entering into the intake before appropriate dilution. The outfall may be located on the northern side of the intake as the flow remains northwards for eight months in a year. Outfall may be placed closer to the shore than the intake as the turbulence inducing the mixing is maximum at nearshore due to the presence of: surf zone, longshore currents, strong orbital currents induced due to shoaling waves, relatively stronger tidal currents, currents due to wave set up etc. Further, placing the intake farther inside the sea than the outfall will help in obtaining relatively clean water.