

NUMERICAL MODEL STUDY OF DISPERSION OF HOT WATER FROM DAHANU THERMAL POWER STATION

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Abstract:

Thermal power plants require considerable amount of water for condenser cooling and the heated water is usually discharged into nearby water bodies such as lake, dam reservoir or coastal areas through suitable outfalls. If the hot water discharged in the water body enters the intake, the cooling water temperature significantly increases, thereby reducing the efficiency of the power plant. The study of the temperature distribution in the receiving waters after the heated discharge is let out helps to choose optimum sites of intake and outfall so that adequate cooling water can be obtained with minimum recirculation. Physical model study for coastal areas is often expensive, time-consuming, labour-intensive and requires large space and water. Hence Numerical Model Study is often preferred. It is essential to check whether the BIS standard of the variable about hot water dispersion in coastal area are fulfilled or violated. If they are violation then applicable solutions need to be suggested. Dahanu, a industrial town in Maharashtra State, India has a thermal power station, which uses sea water for cooling the condenser. The hot water is discharged back into the sea. Numerical model study of mixing zone dispersion and dilution of temperature in the area of existing cooling water intake and hot water outfall has been developed for estimating the temperature dispersion in this region. There are three alternatives including existing intake and outfall was carried out for the outfall locations for the feasibility of the relocation of outfall due to the existing outfall is working with slight temperature increase is entering in to the intake. To avoid the hot water at the intake, the proposed locations were tested using mathematical modelling techniques. MIKE21 HD and ECOLAB modules were used to find out suitable location in the vicinity of offshore region and south side of the creek for more dispersion and dilution of hot water in the sea. After the studies, it concluded that the south side of the creek say about 2 km from the creek is more suitable compared to other outfall locations. The recommended outfall location is suggested from the present studies for more dilution and dispersion of hot water in the coastal environment.

Keywords: Condenser, Efficiency, Recirculation, Dispersion, Thermal Power Station and MIKE21

1. INTRODUCTION

Dahanu, Mumbai, Maharashtra State, India has the potential for commercial and industrial development activities and has witnessed rapid growth during the past few decades. Assessment of mixing zone dispersion and dilution of temperature in the area of existing outfall has been carried out for the temperature dispersion in this region.

An understanding of the physical oceanography of coastal areas provides a basis for the study of processes such as hydrodynamics, advection and dispersion as well as a basis for effective management of the coastal zone. Integrated water management of endangered coastal areas would be able to restore their ecosystems. Numerical models have been developed and applied to coastal engineering problems, in order to simulate hydrodynamic and environmental processes. These models constitute an administrative tool for decision makers in order to apply the right measures to restore the endangered coastal environments.

This study dealt with dispersion and dilution of temperature using 'MIKE 21' 2D software.

1.1. AIM

Determination of dispersion of hot water released in ocean through outfall of the Thermal Power Station at Dahanu, Maharashtra, India.

1.2. OBJECTIVES

- Formulation of numerical model in MIKE 21 and calibrate it by using field data.
- Conduct model simulation and assessment of results with MIKE21 HD & AD suits.
- Determine thermal mapping of the study area.
- Suggest environment friendly solution regarding outfall of Dahanu thermal power station.

1.3. LOCATION

It has established a thermal power station at Dahanu (Lat. 19°57' N, Long. 72°44'30" E) located about 110 km North of Mumbai. The power station has a generating capacity of 500 MW (2 units of 250 MW capacity) and operates on the once through cooling water system. The project is bounded by Savta creek on the North, Dahanu creek on the West, Danda creek on the West as well as South, and the western railway line on the East.



Fig 1: Google Earth Image showing Dahanu Thermal Power Station.

1.4. SPECIFICATION

The sea water under the action of the tide enters from the mouth of the Dahanu creek. Further near the power station, Dahanu creek bifurcates into Savta creek and Danda creek. The required quantity of cooling water, 22.2 m³/s is drawn from the Savta creek and warm water received from the condensers is discharged to Danda creek.

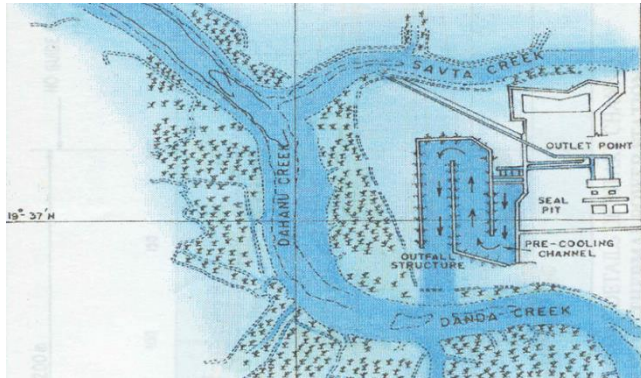


Fig. 2 : Creek System Around Dahanu Thermal Power Station.

2. METHODOLOGY

2.1. DATA COLLECTED:

C MAP, TIPS data, Google Earth satellite photographs and other technical data are available at CWPRS. They are used in this study. Study period taken is: 21/10/2002; 13:05 to 20/12/2002; 13:05.

2.2. SOFTWARE DETAILS:

- ✚ MIKE 21 is a two dimensional water modelling software developed by Denmark Hydraulics Institute(DHI).
- ✚ It consists of different Flexible Mesh (FM),
 - Temperature dispersion, AD
 - Hydrodynamic Module, HD
 - Ecology Module, ECO Lab
- ✚ The modelling system is based on numerical solutions of two dimensional Navier Stokes equation.

2.3. THE HYDRODYNAMIC MODEL MIKE 21-HD:

The Hydrodynamic model MIKE21-HD was used for simulation of water levels and flows in coastal areas. It simulates unsteady two-dimensional flows in coastal areas and is based on the following non-linear vertically integrated 2-D equations of conservation of mass and momentum.

x- direction

$$\frac{\partial u}{\partial t} + \frac{\partial u^2}{\partial x} + \frac{\partial uv}{\partial y} + \frac{\partial wu}{\partial z} = fv - g \frac{\partial \zeta}{\partial x} - \frac{1}{\rho_0} \frac{\partial p_a}{\partial x} - \frac{g}{\rho_0} \int_z^{\zeta} \frac{\partial \rho}{\partial x} dz + F_x + \frac{\partial}{\partial z} \left(v_z \frac{\partial u}{\partial z} \right) + u_z S_z$$

y- direction

$$\frac{\partial v}{\partial t} + \frac{\partial v^2}{\partial y} + \frac{\partial uv}{\partial x} + \frac{\partial wv}{\partial z} = fu - g \frac{\partial \zeta}{\partial y} - \frac{1}{\rho_0} \frac{\partial p_a}{\partial y} - \frac{g}{\rho_0} \int_z^{\zeta} \frac{\partial \rho}{\partial y} dz + F_y + \frac{\partial}{\partial z} \left(v_z \frac{\partial v}{\partial z} \right) + v_z S_z$$

- | | |
|---|--|
| 1. Fluid acceleration | 5. Pressure gradient term |
| 2. Horizontal gradients in the velocity | 6. Acceleration from buoyancy effects |
| 3. Coriolis acceleration | 7. Imbalance of horizontal Reynolds stresses |
| 4. Acceleration from sea | 8. Vertical stresses from the Boussinesq approximation |
| | 9. Acceleration from discharges |

(1)

2.4. THE THERMAL MODEL MIKE 21-AD:

The Advection-Dispersion model MIKE21-AD simulates dispersion of warm water in coastal waters. It is based on the following non-linear vertically integrated 2-D equation of conservation of heat which takes into account advection, dispersion, heat loss to atmosphere, warm water source and sink.

$$\frac{\partial \bar{c}}{\partial t} + u \frac{\partial \bar{c}}{\partial x} + v \frac{\partial \bar{c}}{\partial y} = \frac{1}{h} \frac{\partial}{\partial x} \left(h D_x \frac{\partial \bar{c}}{\partial x} \right) + \frac{1}{h} \frac{\partial}{\partial y} \left(h D_y \frac{\partial \bar{c}}{\partial y} \right) + Q_L C_L \frac{1}{h} - S$$

(2)

Where,

\bar{c} : Depth averaged concentration (g/m³),

D_x, D_y : Dispersion coefficients (m²/s),

u, v : Depth averaged flow velocities (m/s),

h : Water depth (m),

S : Temperature term,

Q_L : Source discharge per unit horizontal area
(m³/s/m²),

C_L : Concentration of the source discharge (g/m³).

In the case of artificially warmed aquatic area, the loss of heat will increase due to long wave radiation, evaporation and convection. This increase in heat loss is included as a decay term FhT , where F is a heat decay coefficient. The following expression is used for computing the decay coefficient.

$$F = 0.2388 / (\rho \cdot C_p \cdot H) (4.6 - 0.09(T_r + T) + 4.06 \cdot W) \exp(0.033(T_r + T))$$

.....(3)

Where, ρ = density of water(kg/m^3), C_p = specific heat, H = water depth (m), T_r = reference temperature($^{\circ}\text{C}$), T = excess temperature ($^{\circ}\text{C}$), W = wind speed (m/s).

2D models are depth averaged in which the variation of parameters over the vertical is not simulated. Rainfall and cyclonic conditions are not considered in this modeling. The model simulates the far field advection-dispersion of the warm water. In case of water, conduction is insignificant while advection/convection is important and is considered in the model.

2.5. LIMITATION AND ACCURACY OF MODEL:

Since MIKE21 is a 2D model, its major limitation is that it gives vertically averaged currents and temperature rise at each grid point under the assumption of well mixed condition. It is not capable of simulating accurately the near-field dispersion of warm water, while it can simulate far field dispersion more accurately. If the water body is well mixed, it can simulate the far field dispersion of warm water reasonably accurately. As large region can be simulated by this model, it can give guidelines for refinement by 3D mathematical/physical model.

2.6. JUSTIFICATIONS:

- Wind direction measurements were not made, results are obtained from previous reports.
- Water temperatures at various locations were determined from the numerical model and results were plotted in the form of Temperature Contours higher than the ambient (sea) water temperature.
- For the sake of illustration the temperatures are given after a duration of 24 hours from the occurrence of low water.
- Range of ambient water temperature varies between 25°C to 27°C .
- Outfall water temperature varies between 7°C to 10°C plus ambient water temperature.

3. NUMERICAL MODELLING

3.1. NUMERICAL MODELLING STEPS:

1. Pre-processing
 - a) Bathymetry
 - b) Tides
 - c) Currents
 - d) Ambient Water Temperature
 - e) Outfall water Temperature
 - f) Outfall Discharge
2. Model Simulation
 - a) Hydro-Dynamic model formulation
 - b) Advection Dispersion model formulation
 - c) Ecolab model formulation
3. Post Processing
 - a) Preparation of plots for :
 - i. Tides (HD)

- ii. Currents (HD)
- iii. Water Temperature (AD)
- iv. BOD (ECOLAB)
- v. DO (ECOLAB)
- vi. NITRATES (ECOLAB)

b) Comparison with observed data

4. Analysis of Results
5. Conclusions & Recommendations

3.2. PHASE DIFFERENCE:

Phase difference between North and South tides is taken as 10 minutes in this model. It is nothing but, suppose 1m height of tide occurs in North Boundary at 3 pm, then same 1m height of tide will occur in South boundary at 3:10 pm. Following fig. no. 3 is showing separate North and South tidal levels and fig. no. 4 is showing the comparison of both North and South tidal levels, which seems to be similar.

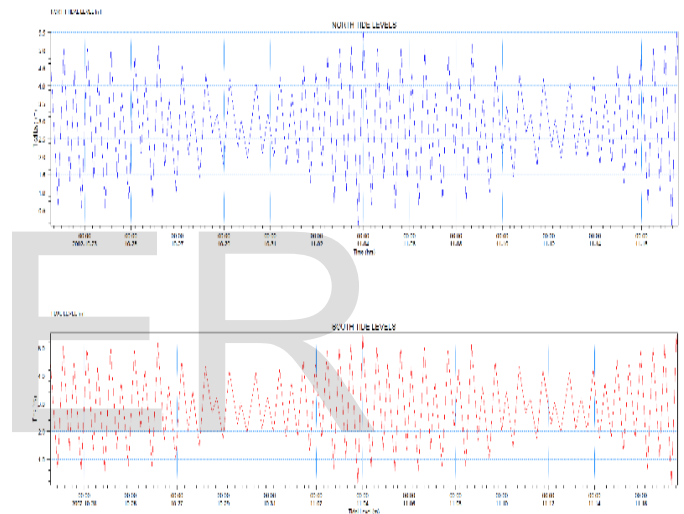


Fig. 3 : North and South Tidal Levels.

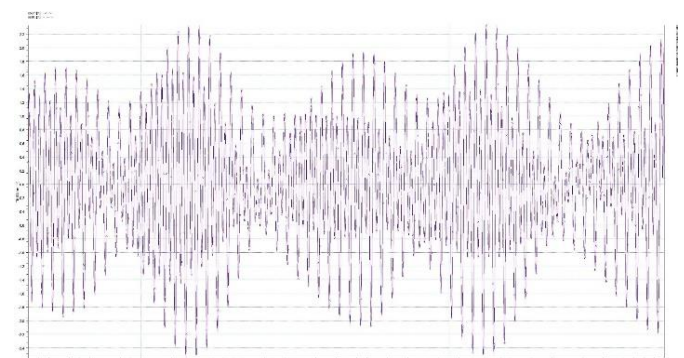


Fig. 4: Comparison of North and South Tidal Levels.

3.3. MODEL SIMULATION:

There are three open boundaries in the sea portion of the model. At the northern and southern open boundaries, tidal variations are used as boundary conditions and at the western open boundary no flow condition is used.

Model simulation data used for HD & AD model formulation is as follows:

No. of Time Steps	518400
Time Step	10 seconds
Duration	Two Months
Triangular Mesh Grid Size	50 m – 1416.78 m
Study Area	168 km ²
Wind Speed	5 m/s
Surface Elevation	4.47 m (Initial Tidal Height)
Frequency of result stored	30 min
Nodes in file	1257
Manning's constant	32 m ^{1/3} /s

3.4. TOTAL RUNS OF THE MODEL ARE AS FOLLOWS:

Run no.	Discharge (cumecs)	Current Direction	Temp. At Outlet (°C.)	Wind Direction (degrees)	Distance of ambient temp. from existing outfall (km)	Recirculation At Inlet 27° C+
1	45	North	7	0	2.4	5.5
2	45	North	7	240	2.5	5.5
3	45	North	7	300	2.5	5.5
4	45	North	10	0	2.5	8
5	45	North	10	240	2.4	8
6	45	North	10	300	2.4	8.5
7	45	South	7	0	2.4	6
8	45	South	7	240	2.2	5.5
9	45	South	7	300	2.3	5.5
10	45	South	10	0	2.25	8
11	45	South	10	240	2.1	8
12	45	South	10	300	2.15	8.5
13	90	North	7	0	3.95	Above 6.5
14	90	North	7	240	2.9	Above 6.5
15	90	North	7	300	3	Above 6.5
16	90	North	10	0	3	Above 9.6
17	90	North	10	240	2.8	Above 9.6
18	90	North	10	300	2.85	Above 9.6

18	90	South	7	0	2.8	Above 6.5
20	90	South	7	240	2.75	Above 6.5
21	90	South	7	300	2.75	Above 6.5
22	90	South	10	0	2.75	Above 9.6
23	90	South	10	240	2.6	Above 9.6
24	90	South	10	300	2.7	Above 9.6

3.5. HYDRODYNAMIC MODEL CALIBRATION:

Before operating the models for predictive cases it is required to calibrate the models using observed data. Tidal levels were available. Tidal boundary conditions of the model were derived from a larger and coarse grid model of grid size. At the seaward boundary no flow was assumed.

Several trial runs of hydrodynamic model were made by varying Manning's bed roughness to get the observed flow field in the model region. The hydrodynamics in the model region was simulated for existing conditions and was calibrated against field data on tidal levels. The time history of observed and computed tidal level is shown in Fig. no. 5. The observed and computed Tidal levels are matching satisfactorily.

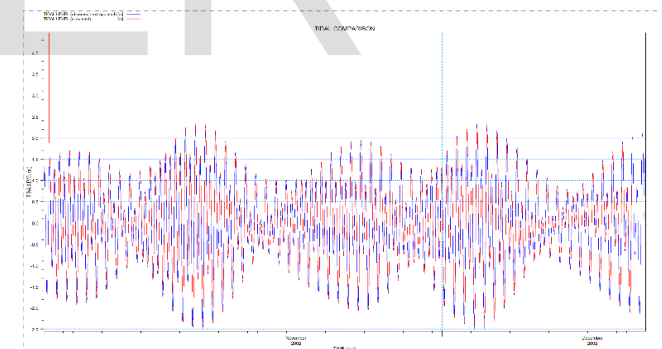


Fig. 5 : Comparison of Observed & Simulated Tidal Level Graph.

3.6. POST PROCESSING:

Post processing includes preparation of plots after model simulation, using simulated data occurred from total runs, and comparison of simulated data with observed data.

In the existing situation, no thermal contours data at the site was available. Hence the thermal model cannot be calibrated against observed data. However, based on the past experience and referring similar studies from literature, the calibrating parameters of the thermal model i. e. dispersion coefficients in x and y directions, namely, Dx and Dy were selected.

Run 1:

Time history of temperature rise at the intake and temperature field after 60 days obtained by the thermal model are shown in Fig. no. 6. From this figure it could be seen that after 60 days, thermal plume (say thermal spread up to 0.5°C contour) is becoming shore attached. As current is effectively southward, the plume extends downstream (southward) for longer distance than its upstream (northward) extension. The downstream extension of the plume is more than 5 km, while the upstream extension is about 0.5 km. The cross-shore extension of the plume is up to about 2.4 km from shore. Recirculation is 5.5°C at inlet.

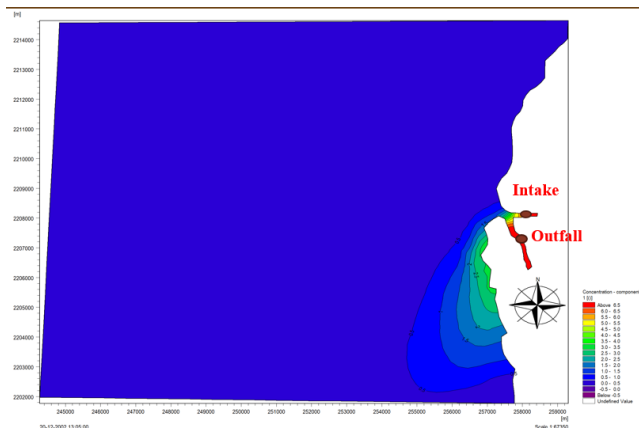


Fig. 6 : Distribution of Temperature in the Model Region
Discharge $45 \text{ m}^3/\text{s}$, currents from North, 7°C , 0° Wind
Direction, Dispersion Distance 2.4 km.

The time history of temperature rise at the junction of creeks and coastal region also shown in the fig. no. 7 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 6°C .

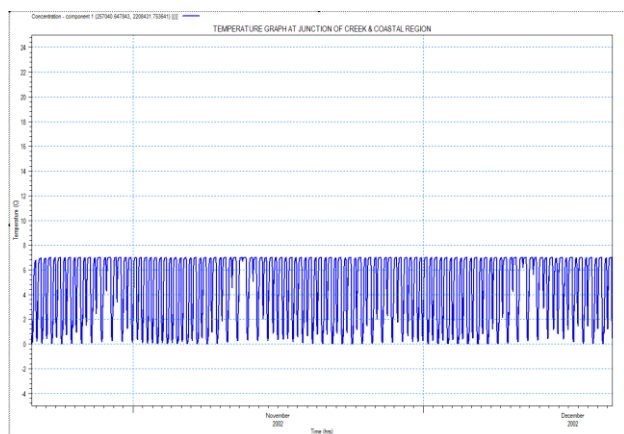


Fig. 7 : Time History of Temperature in the Model Region at
Junction of Creek and Sea for Run 1.

The time history of temperature rise at the outfall also shown in the fig. no. 8 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 7°C .

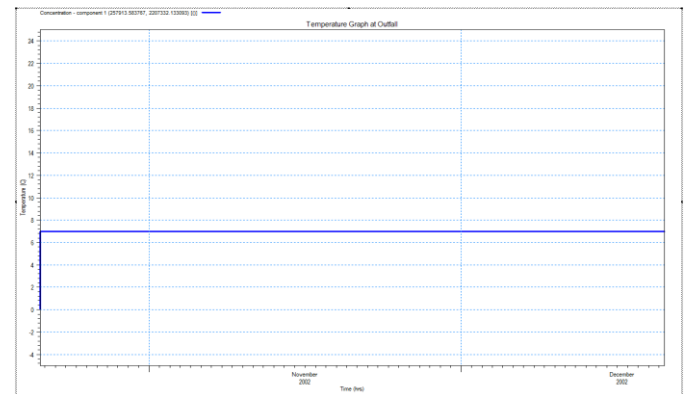


Fig. 8 : Time History of Temperature in the Model Region at
Outfall for Run 1.

RUN 7:

Time history of temperature rise at the intakes and temperature field after 60 days obtained by the thermal model are shown in fig. no. 9. From this figure it could be seen that after 60 days, thermal plume (say thermal spread up to 0.5°C contour) is becoming shore attached. As current is effectively northward, the plume extends downstream (northward) for longer distance than its upstream (southward) extension. The downstream extension of the plume is more than 0.5 km, while the upstream extension is about 6 km. The cross-shore extension of the plume is up to about 2.4 km from shore. Recirculation is 6°C at inlet.

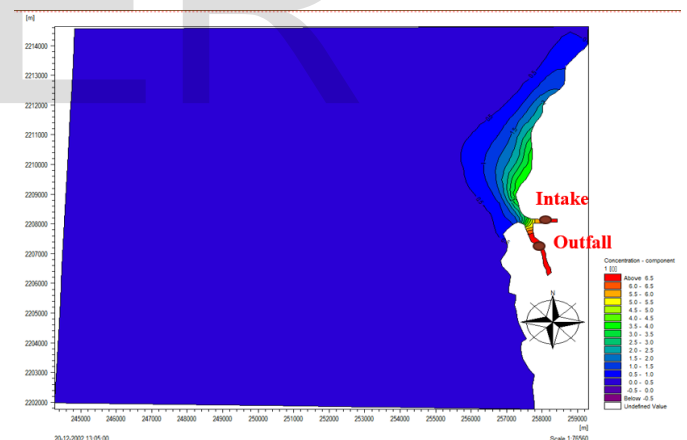


Fig. 9 : Distribution of Temperature in the Model Region
Discharge $45 \text{ M}^3/\text{s}$, currents from South, 7°C , 0° Wind
Direction, Dispersion Distance 2.4 Km.

The time history of temperature rise at the junction of creeks and coastal region also shown in the fig. no. 10 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 6°C .

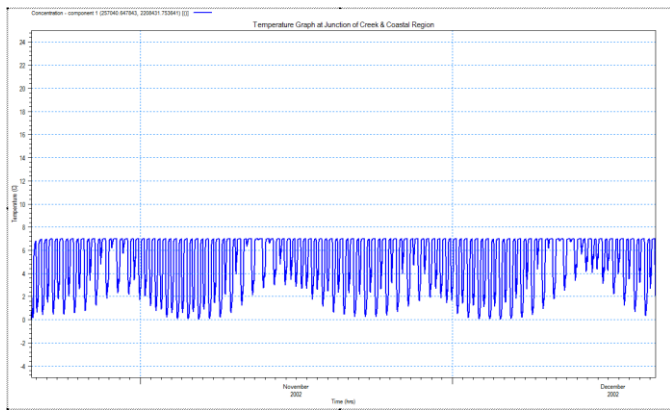


Fig. 10 : Time History of Temperature in the Model Region at Junction of Creek and Sea for Run 7.

The time history of temperature rise at the outfall also shown in the fig. no. 11 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 7°C .

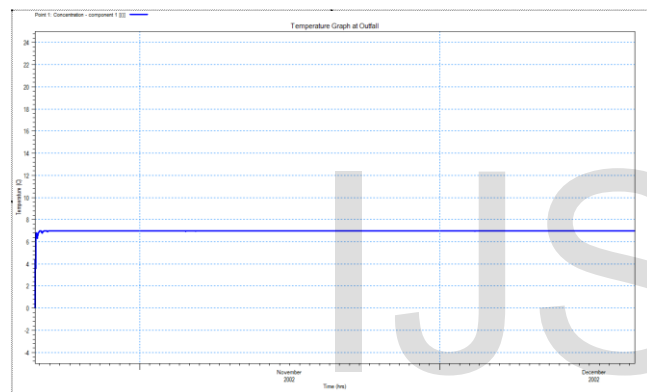


Fig. 11 :Time History of Temperature in the Model Region at Outfall for Run 7.

3.7. VALIDATION OF THE MODEL:

Validation of this Model is carried out with the help of water temperature observed and simulated at intake. Following fig. no. 12 is showing the temperature validation graph at inlet. Blue colour is showing Simulated water Temperature and Red colour is showing Observed water Temperature at intake. Both observed and simulated graphs are matching satisfactory.

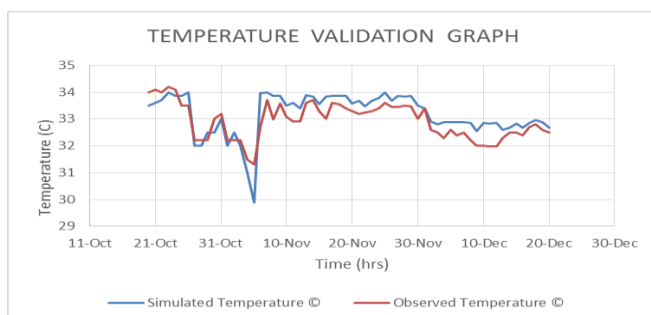


Fig. 12 : Temperature Validation Graph at Inlet.

3.8.RECOMMENDATION PLOTS

1. Offshore Outfall, for currents from North, $45\text{ m}^3/\text{s}$ Discharge, 7°C , 0° wind Direction.

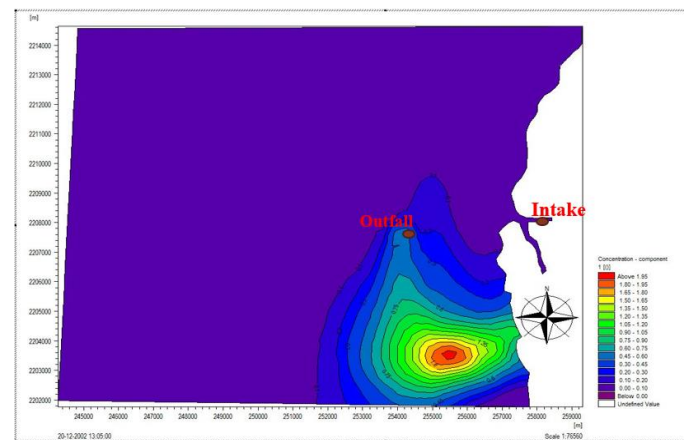


Fig. 13 : Distribution of Temperature in the Model Region Offshore Outfall.

Distribution of temperature rise at the outfall and temperature field after 60 days obtained by the thermal model are shown in figs. no. 13. From this figure it could be seen that after 60 days, thermal plume (say thermal spread up to 0.5°C contour) is becoming shore attached. As current is effectively southward, the plume extends downstream (southward) for longer distance than its upstream (northward) extension. The downstream extension of the plume is more than 5 km, while the upstream extension is about 0 km. The cross-shore extension of the plume is up to about 6 km from shore. No recirculation at inlet.

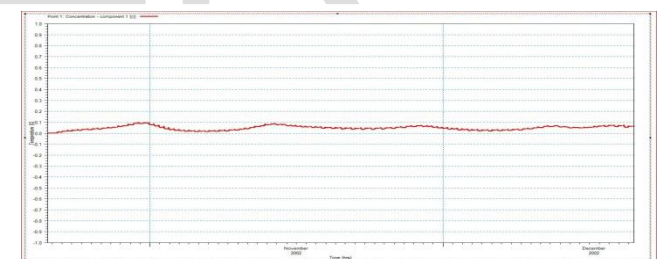


Fig. 14 : Time History of Temperature in the Model Region at Inlet for Offshore Recommended Outfall.

The time history of temperature rise at the intakes also shown in the fig. no. 14 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 0.1°C .

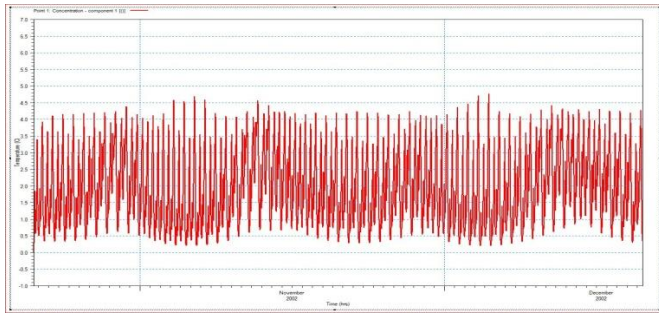


Fig. 15 : Time History of Temperature in the Model Region at Outfall for Offshore Recommended Outfall.

The time history of temperature rise at the intakes also shown in the fig. no. 15 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 3^0C .

2. Offshore Outfall, for currents from South, $45\text{ m}^3/\text{s}$, 7^0C , 0^0 wind Direction.

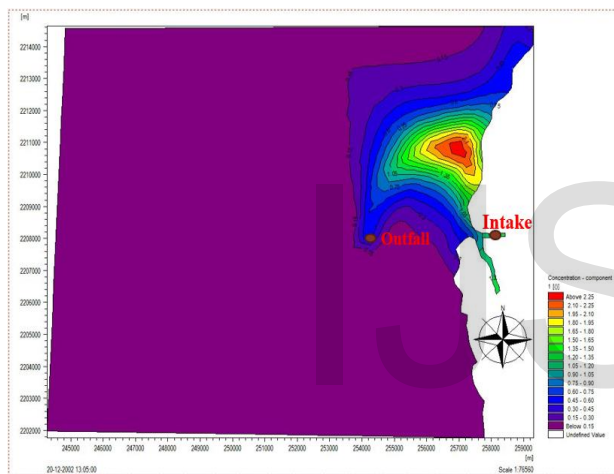


Fig. 16 : Distribution of Temperature in the Model Region Offshore Outfall.

Distribution of temperature rise at the outfall and temperature field after 60 days obtained by the thermal model are shown in fig. no. 16. From this figure it could be seen that after 60 days, thermal plume (say thermal spread up to 0.5^0C contour) is becoming shore attached. As current is effectively northward, the plume extends upstream (northward) for longer distance than its downstream (southward) extension. The upstream extension of the plume is more than 7 km, while the upstream extension is about 0.5 km. the cross-shore extension of the plume is up to about 3.5 km from shore. 1.05^0C recirculation at inlet.

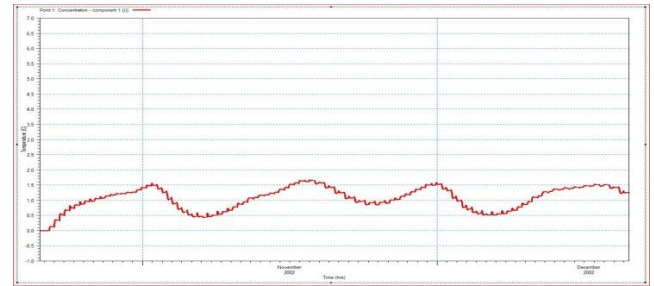


Fig. 17 : Time History of Temperature in the Model Region at Inlet for Offshore Recommended Outfall.

The time history of temperature rise at the inlet also shown in the fig. no. 17 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 1^0C .

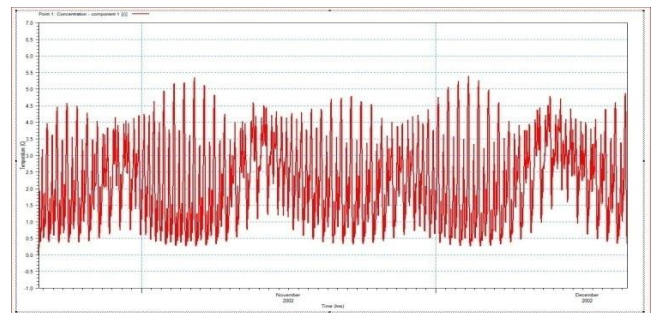


Fig. 18 : Time History of Temperature in the Model Region at Outfall for Offshore Recommended Outfall.

The time history of temperature rise at the outfall also shown in the fig. no. 18 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 3^0C .

3. Onshore Outfall, North Currents, $45\text{ m}^3/\text{s}$, 7^0C , 0^0 wind Direction

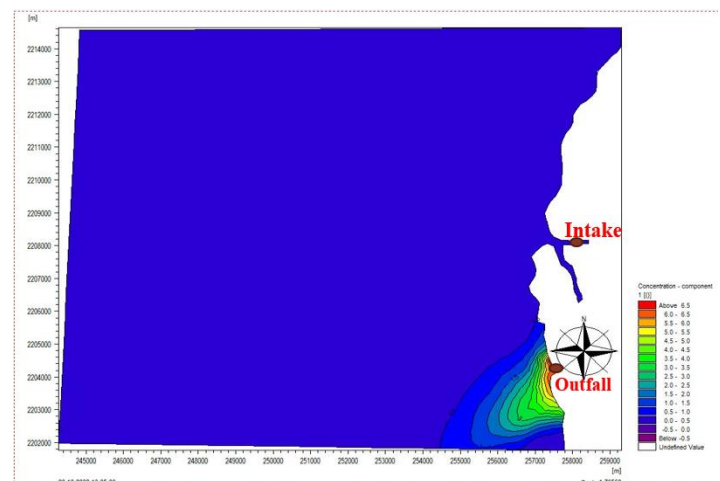


Fig. 19 : Distribution of Temperature in the Model Region Onshore Outfall.

Distribution of temperature rise at the outfall and temperature field after 60 days obtained by the thermal model are shown in fig. no. 19. From this figure it could be

seen that after 60 days, thermal plume (say thermal spread up to 0.5°C contour) is becoming shore attached. As current is effectively southward, the plume extends downstream (southward) for longer distance than its upstream (northward) extension. The downstream extension of the plume is more than 2.5 km, while the upstream extension is about 0.5 km. The cross-shore extension of the plume is up to about 2.5 km from shore. No Recirculation at Inlet.

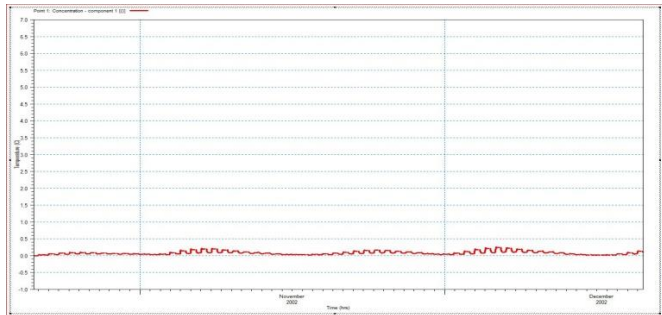


Fig. 20 : Time History of Temperature in the Model Region Inlet, for Onshore Recommended Outfall.

The time history of temperature rise at the intakes also shown in the fig. no. 20 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 0.0°C .

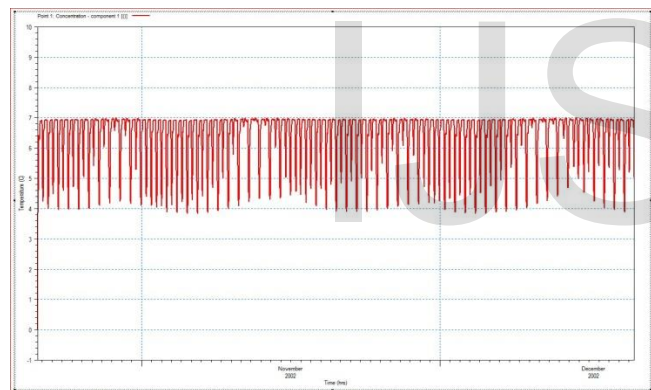


Fig. 21 : Time History of Temperature in the Model Region Outfall for Onshore Recommended Outfall.

The time history of temperature rise at the outfall also shown in the fig. no. 21 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 6°C .

4. Onshore Outfall, South Currents, $45 \text{ m}^3/\text{s}$, 7°C , 0° wind Direction

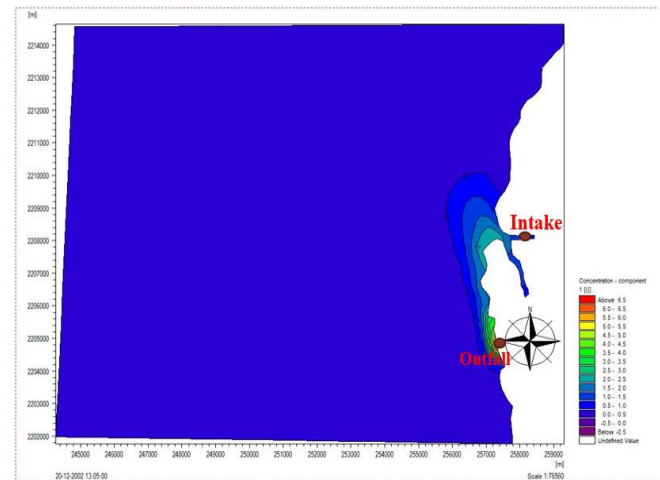


Fig. 22 : Distribution of Temperature in the Model Region Onshore Outfall.

Distribution of temperature rise at the outfall and temperature field after 60 days obtained by the thermal model are shown in fig. no. 22. From this figure it could be seen that after 60 days, thermal plume (say thermal spread up to 0.5°C contour) is becoming shore attached. As current is effectively northward, the plume extends upstream (northward) for longer distance than its downstream (southward) extension. The downstream extension of the plume is about 0.5 km, while the upstream extension is about 3.5 km. The cross-shore extension of the plume is up to about 0.5 km from shore. No recirculation at inlet.

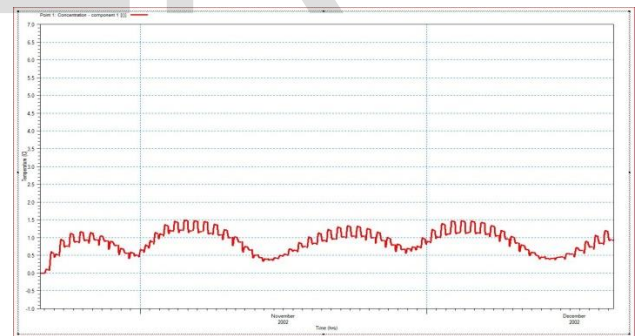


Fig. 23 : Time History of Temperature in the Model Region at Inlet for Onshore Recommended Outfall.

The time history of temperature rise at the intakes also shown in the fig. no. 23 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 1°C .

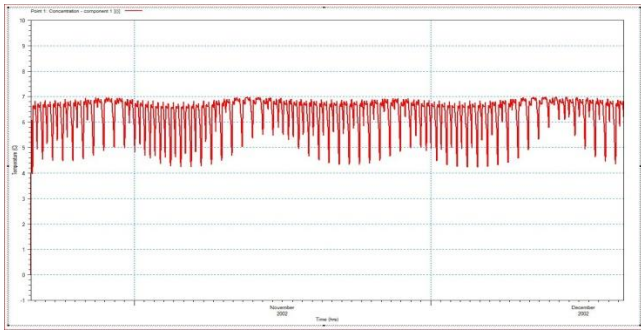


Fig. 24 : Time History of Temperature in the Model Region at Outfall for Onshore Recommended Outfall.

The time history of temperature rise at the intakes also shown in the fig. no. 24 indicates oscillations in temperature rise according to tidal phase. The average temperature rise at the intake is of the order of 6.5⁰ C.

3.9. COMPARISON TABLE OF EXISTING AND RECOMMENDED OUTFALL LOCATIONS:

Outfall Locations	Currents	Recirculation Temperature (Degrees C)	Efficiency Decreased %
Existing	North	5.5	5.5
	South	6	6
Option A (Offshore) 2.4 km away from existing outfall	North	0	0
	South	1.05	1.05
Option B (Onshore) 2 km away from existing outfall	North	0	0
	South	0	0

4. CONCLUSIONS:

1. The existing regulations require that the outfall water temperature from a thermal power station should not be greater than 7^o C above the ambient (in the sea) water temperature.
2. Recirculation of the hot water from the outfall getting back through the intake reduces the cooling efficiency & hence the output of the power station.
3. The field data as well as the results of Numerical Model Study have shown that recirculation is taking place at the intake of power station under the present conditions.
4. Conducting Numerical Model Study is a method which is used, worldwide for reducing recirculation at thermal power station. The model used for the present study was MIKE 21 developed by Danish Hydraulics Institute (DHI), Denmark; which is found to be a successful tool in this regard.

5. Different methods are available for reducing or avoiding hot water recirculation. The present study was restricted to conducting a two dimensional Numerical Model Study, mainly to study the effect of changing the location of outfall.
6. All the relevant natural parameters were included in the study, namely strength & direction of Tides, Currents & Wind. The current direction from North to South was not significant because Cooling Water (CW) intake is located on the North side.
7. The presently developed Numerical Model can be used in the future for different conditions, such as change in outfall discharge or change in natural conditions such as geometry and weather parameters.
8. Hence one onshore location & one offshore location were examined on the Numerical Model.
9. The study showed the following,
 - A. Although outfall located 2.4 km away from the shore gave satisfactory results, this option would be very expensive.
 - B. If the outfall is located onshore 2 km on the south side of the intake, the rise of ambient water temperature was within the presently acceptable limits.
10. The “B” option can be easily incorporated in the form of an open channel, which will also have the benefit of heat loss through Conduction and Evaporation.

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