Modeling of thermal pollution in the northern coastal area of the Persian Gulf and its economical and environmental assessment

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Abstract

The Persian Gulf is one of the aquatic ecosystems which has recently been faced with different pollutions. Cooling water discharges due to various industries such as power plants can cause important disorders on the present ecosystem balance and on aquatic creatures because of their high temperature. Thermal pollution leads to their migration, creates a potential for new coming species which in turn can thoroughly change the marine ecosystem feature. In this research, thermal pollution due to the Bandar Abbas Thermal Power Plant (BATP) development plan was modeled using MIKE21 software. In order to avoid a decrease in the power plant efficiency in the development plan, the distance between the inlet and outlet was determined by comparing the results of different scenarios and economical aspects. After determining the distance between the inlet and outlet, the water temperature in the coastal area was compared with the standards of the Iranian Department of the Environment (DOE). The model results show that the water temperature, in Bandar Abbas coastal area, exceeds the permissible limit (3°C) at a distance equal to 200 m from the discharging location, and in order to reduce its harmful impacts, some suggestions are made to reduce the associated thermal pollution.
Keywords: power plant, thermal pollution, modeling, Persian Gulf, MIKE21.

1 Introduction

Chemical industries, fossil fuel and nuclear power plants use lots of water for cooling purposes and return this water to the environment at a higher temperature. The hot water interferes with the natural conditions in the sea, lake or river affecting aquatic life. This is thermal pollution when heat acts as a pollutant [2]. Hitherto, the largest quantities of heat have been due to cooling water discharge from power plants. In the southern part of Iran, cooling water from Boushehr, Kish and Bandar Abbas power plants is directly discharged to the coastal area of the Persian Gulf, which has harmful consequences on the marine ecosystem. In this research, thermal pollution distribution due to the Bandar Abbas Power plant development plan in coastal area was modeled by software and the water temperature increase was compared with the standards of Iranian Department of the Environment (DOE), and finally some suggestion was made to reduce the associated thermal pollution. Bandar Abbas Steam Power Plant has four steam units, and the power generation of each of them equals 320 MW. It is located at (56° 7' E, 27° 8' N) near the coast of the Persian Gulf, [8]. The required water for the condenser, cooling towers and water desalination units is 50 m^3/s, which is taken from the Gulf. Two adjacent concrete channel discharge the sewage into the Gulf. In the power plant development plan, it was decided that two steam units be added (the power generation of each of them equals 325 MW [8]). Therefore the total discharge for the power plant will reach 75 m^3/s and three adjacent concrete channels will discharge the whole sewage in a location so that the hot water will not affect the efficiency of the power plant more than a specific amount, fig. 1.

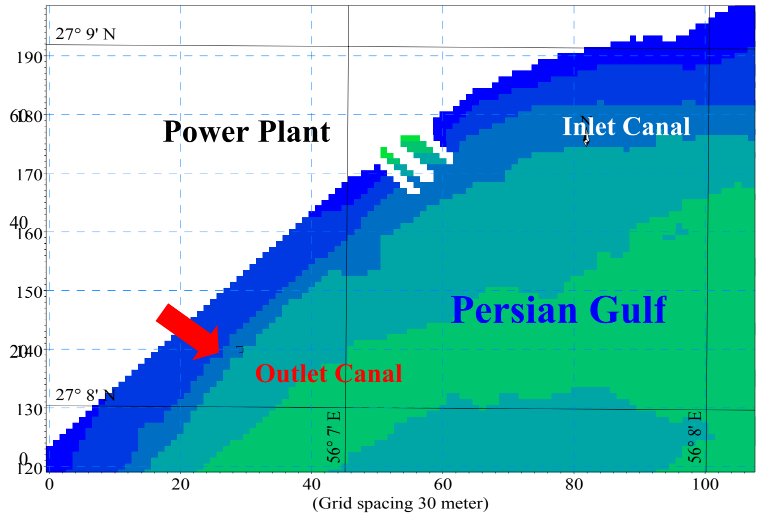

Figure 1: Probable inlet and outlet location in BATP development plan.

2 Methodology

2.1 Input and output

The input data used in Mike21 model are:
- Bathymetric data.
- Stationary tidal variations; two stations including Bandar Abbas old port (at 27° 10'N -56° 17'E) and Shahid Rajaii port (at 27° 6'N - 56° 4'E) are located on the open boundaries of the regional model, and one station, Bandar Abbas new port (at 27° 8'N- 56° N 12'E) is inside the domain.
- Annual wind rose in which the prevailing and the maximum wind speed from the south are about 4 and 15 (m/s), respectively; and the maximum wind speed from the south-west is about 13 m/s (durations: 3 hours).
- Annual wave rose in which the prevailing and the maximum significant wave height from the south are 0.3 m (period: 2-3 s) and 1.5 m (period: 4-5 s), respectively.
- Mean coastal water temperature in the summer is about 36 degrees centigrade, and the mean water temperature discharged from the power plant is about 42 degrees centigrade (so, considering the water ambient temperature equal to zero, the outlet water excess temperature used in modeling reaches 6°C).
- Water discharge from the power plant channel is 75 m^3/s in the development plan.

2.2 Selecting model area and grid spacing

For hydraulic modeling, three areas about 25km×25km (regional model), 12km×14km (transitional model), 7km×7km (local model) with grid spacing respectively 300m×300m, 100m×100m and 30m×30m are chosen in order to transfer the water velocity and height from each larger model to the open boundary of the smaller one. For wave modeling, the grid spacing for the transitional model is 100m×300m and for the local one is 30m×30m. The largest model is extended such that there is a tidal station nearly at each end of the open boundaries. The transitional model is extended in which the flow pattern due to wave and wind to be computed, and the local model is extended to encompass the heated area thoroughly.

2.3 Boundary conditions

As mentioned previously, there are tidal stations at the open boundaries of the regional model. So, the water surface elevation data from the tidal stations is specified at the open boundaries to execute the hydrodynamic model run.

At the transitional model open boundaries the required boundary conditions (water level variations and fluxes) are transferred from the regional hydrodynamic model output. Besides, in this area, wave parameters are specified at the offshore boundary of the region in NSW module. After executing the local NSW model run, the wave parameters are extracted as input for the NSW local model in order to compute the radiation stresses (as input for the local hydrodynamic model).

At the local model open boundaries the required boundary conditions are transferred from the transitional model to the open boundaries. Hydrodynamic and heat transfer modeling in the local area is carried out at the same time. In this area at the open boundaries, as the temperature data is not sufficient, the mean water temperature is specified.

2.4 Model calibration/verification

In order to rely on the results of any modeling study, the model should be calibrated and verified to a satisfactory accuracy. In the following the calibration and verification of the models are described:

2.4.1 Hydrodynamic model calibration/verification

Tidal variation data for three stations was available. Two stations locate nearly on the open boundaries of the largest model. The data was applied for one day on the open boundaries and after simulation; the extracted data from model at the third station was compared with the real data. The model was calibrated by changing the bed resistance factor until the error is less than 15 percent regarding the real data mean value. For verification, the data was applied for two other days on the open boundaries without changing any factor. After simulation, the error was less than 15 percent and it wasn't necessary to carry out any verification. The result for calibration is shown in fig. 2.

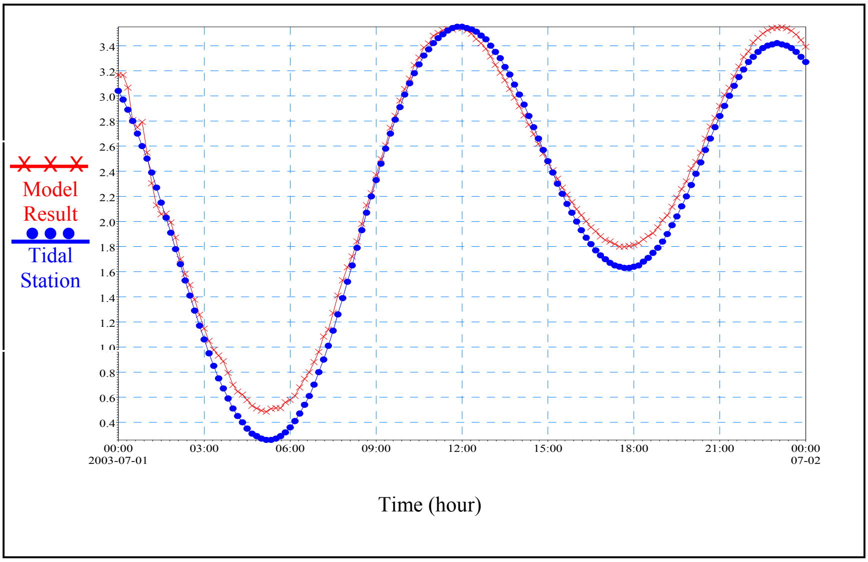

Figure 2: Comparing real water height variations (Relative to Chart Datum) with model results for calibration.

Table 1: Model calibration results for different parameters and conditions.

Parameters	Model Run Conditions	Dispersion Coefficient (m^2/s)	Inlet Mean Excess Temperature (°C)	Temperature difference (°C)
Dispersion coefficient	Prevailing wind and wave	1.5	1.09	0.2
		5	0.91	
Wave and wind	Without wind and wave	1.5	0.8	0.5
	Max. wind and wave from South-West		1.27	
	Without wind and wave	1.5	0.8	0.3
	Prevailing wind and wave		1.09	
	Prevailing wind and wave	5	0.74	0.2
	Max. wind and wave from South		0.91	
	Max. wind and wave from South-West	1.5	1.27	0.2
	Prevailing wind and wave		1.09	
Outlet channel distance from current location	Prevailing wind and wave (outlet is located 190 m far from the current outlet location toward west along the shore line)	5	0.84	0.07
	Prevailing wind and wave (current outlet location)		0.91	
	Prevailing wind and wave (current outlet location)	5	0.91	0.4
	Prevailing wind and wave (outlet is located 300 m far from the current outlet location toward south)		0.5	

2.4.2 Advection dispersion model calibration / verification

Considering that the excess temperature in the inlet channel is not to be more than a specific value (in order to prevent decrease in power plant efficiency), the simulation was carried out with different scenarios, mentioned below, in which the highest tidal variations in the year occur (in order to discover the worst condition in inlet due to hot water recirculation).

- Model run, considering the tidal variations, without considering the wind and wave.
- Model run, considering the tidal variations and maximum southwest wind and wave.
- Model run, considering the tidal variations and prevailing south wind and wave; by considering different locations for discharging the hot water at the current outlet location, in the sea and along the shoreline.

- Model run, considering the tidal variations and max south wind and wave.

There were not enough water temperature data to calibrate the model and to determine the heat dispersion coefficient. Therefore, in order to find out how much the dispersion coefficient affects the inlet temperature, the simulation was carried out by different dispersion coefficient values.

According to these simulations, it was concluded that various dispersion coefficients have little effect on inlet temperature, and it does not affect the simulation results so much (see table 1), [1, 4, 5, 6, 9].

2.4.3 Wave model calibration/verification

As no wave measurements were available, no calibration was carried out. However, temperature variations due to various wind and wave conditions show a little effect on the inlet temperature (see table 1), [3].

3 Results

3.1 Model results

The max south-west wind and wave (causing the critical situation in inlet) makes an increase of 2.5°C at the inlet water temperature, at maximum. Increasing the outlet distance from the inlet and moving toward the sea or along the shoreline, can cause a decrease in inlet water temperature (table 1).

At the end of the low water (ebb) and beginning of high water (flow) the highest temperature occurs at the inlet.

Although the highest temperature occurs in simulation with considering the tidal flow and max south-west and west wind and wave, these scenarios were not used to determine the outlet distance from the inlet (because of the infrequency of their occurrence – about 1 percent), and the best scenario for outlet distance determination is on the basis of simulation with considering the tidal flow and prevailing wind and wave (see fig. 3 for its excess water temperature distribution at Bandar Abbas power plant coastal area).

Temperature variations in the inlet, due to dispersion coefficient variations is little (about 0.2 - 0.5°C).

Consequently, determination of the distance between the outlet and inlet is on the basis of the scenario in which tidal flow with prevailing south wind and wave is considered. This scenario shows higher water temperature (as mentioned below) than the real situation. Therefore, the results obtained from it define the worst condition at the inlet; and the outlet channel distance to the inlet can be determined.

In the hydrodynamic simulation the time series tidal flow data and a constant value for wind and wave is used. The constant value magnifies the effect of the wind and wave, and increases the max inlet water temperature more than the real situation.

The model is 2D and heat dissipation is not due to mixing with the lower layers of the water, and heat dissipation is only to the atmosphere. Therefore, the simulation show higher values comparing the real situation.

The simulation was carried out for one day with highest water variations (ebb and flow), so it magnifies the inlet water temperature more than the real situation.

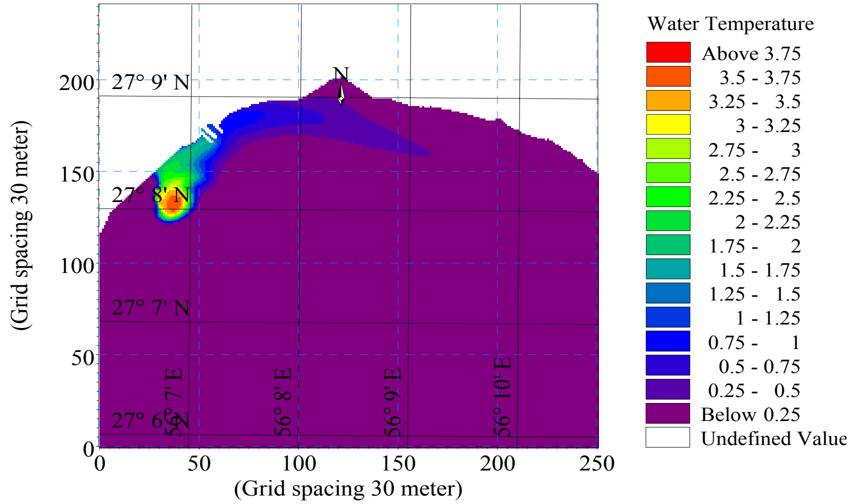

Figure 3 Excess water temperature distribution at Bandar Abbas power plant coastal area at 9 hours after simulation for the selected scenario.

3.2 Economical comparison of different alternatives for discharging cooling water into the sea in BATP development plan

The most important part in each project is to choose a cost-effective alternative. In this survey, to discharge the cooling water, three following alternatives are compared as of economical aspects.

- Construction of an outlet channel, which is 500m. in length in BATP development plan parallel to the current outlet, which costs 634147,8 USD.
- Construction of three parallel outlets for discharging the whole water – used by the power plant – which is 690 m. in length (the discharge location is 190 m. far from the current outlet along the shoreline toward west), which costs 1384797,8 USD.
- Construction of an outlet which is 500 m. in length for discharging the excess discharge (in the BATP development plan) and parallel to the current one; and pipe laying is 300 m in length in to the sea toward the south to discharge the whole amount of cooling water, which costs 5118548 USD (pipe laying under the sea has the most effect on cost growth).

As it was expected, the first alternative is the cheapest and most effective one.

4 Discussion and conclusion

After reviewing the simulation results, the scenario considering the prevailing south wind and wave without changing the current location of the outlet causes the greatest excess temperature in the inlet, and either the temperature does not exceed more than an allowed amount. In addition, construction of an outlet channel (500 m. in length) parallel to the previous one, and construction of a structure for discharging the added flow (in the BATP development plan) into the sea is the cheapest and the most cost-effective one. Therefore, the location of the outlet adjacent to the current one is recommended for discharging cooling water in this project.

4.1 Thermal pollution environmental assessment in BATP development plan

According to the Iranian Department of the Environment (DOE) standards, the hot water discharge into a water resource must not make an increase in the water ambient temperature of more than 3 degrees Celsius in a distance equal to 200 m far from the discharging location. The model result shows that the water temperature in Bandar Abbas coastal area exceeds the permissible limit and in order to decrease its harmful impacts, some considerations, mentioned below, should be applied, fig. 4.

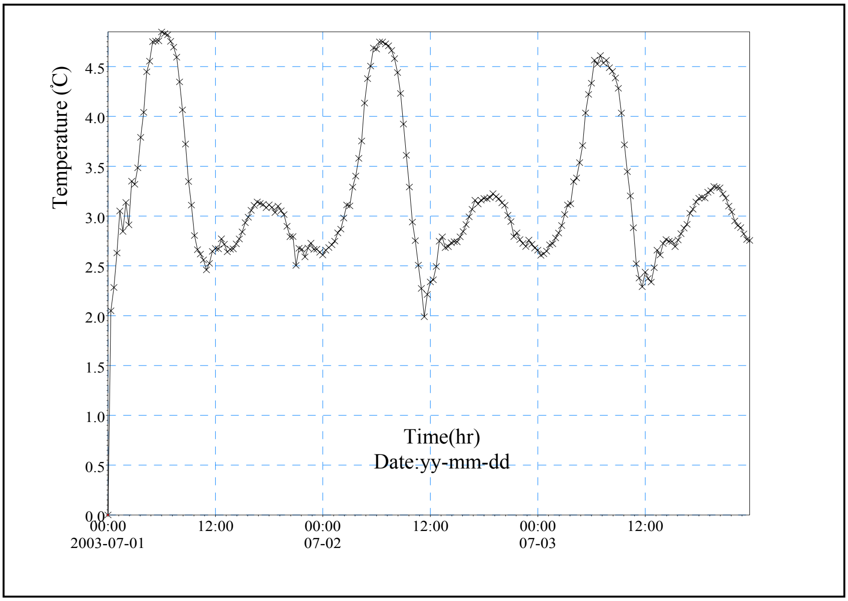

Figure 4: Water temperature variations 200 m from the discharging location in Bandar Abbas coastal area.

5 Suggestions

In order to simulate each phenomenon by software, it is necessary to collect various data for a long period of time to use them as an input for the model. In this research, lack of data was the basic problem. Availability of a complete time series data is too important to accomplish a simulation properly and to use the results of these basic models for later predictions and purposes. The final goal of data collection is to calibrate and verify a simulation. Therefore, the data – mentioned below – is necessary to be collected for the Bandar Abbas region from meteorological stations in land and sea, and buoys:

Wind direction and velocity, precipitation, evaporation, water temperature, water flow direction and velocity, wave conditions such as height, period, and direction and so on.

There are various methods to reduce and control the thermal pollution problem. Among which are: using the cooling towers – not recommended in this project because of existence of a high amount of dissolved matters in the sea water that can be deposit in the pipes –, dilution through the outlet way by adding sea water that does help to reduce the temperature, discharging the cooling water into the ponds for some time to get cooler, and finally, dividing the cooling water amount and discharging each portion of it in different locations to reduce its harmful effects.

References

[1] Ekebjaerg, L. and P. Justesen, An explicit method scheme for advection-diffusion modeling in two dimensions. Computer methods in applied mechanics and engineering, North Netherlands, 88: 287-297, 1991

[2] Kummar, U. and Kakrani, B. , Water, Environment and Pollution, Agrobios, India, 2000

[3] Mahboob-ul-Kabir, M. et al., Past Studies and Further Scopes on Wave modeling in the Coastal Region of Bangladesh, Conference proceedings of the 1st Asia Pacific DHI Conference, Bangkok, 2002

[4] MIKE 21 Environmental Hydraulics Advection, Dispersion Module, scientific Documentation, DHI Software, 2003

[5] MIKE 21 Environmental Hydraulics Advection, Dispersion Module, Reference Manual, DHI Software, 2003

[6] MIKE 21 Coastal Hydraulics and Oceanography, Hydrodynamic Module, Scientific Documentation, DHI Software, 2003

[7] MIKE 21 Nearshore Spectral Wind-Wave Module, Scientific Documentation. DHI Software 2003

[8] Samadi, R., Correlation assessment of management and planning with the environment in Bandar Abbas power plant, Master of science thesis, Tehran University, 1997

[9] U.S. Army corps of Engineers, Engineering and Design Coastal Inlet hydraulics and Sedimentation, Manual No.1110-2-1618, 1995