Thermal Plume Assessment of Nuclear Power Plant Using Numerical Model

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Abstract

Bangladesh has provided additional emphasis to enhance its power and energy production as well as maintenance. Integrated application of numerical modeling tools has increased over the years, and fact-finding on environmental implications due to plume distribution of nuclear power plants have perceived wide recognition. This study attempts to understand and simulate a Hydrodynamic Numerical Plume Model namely, the Cornell Mixing Zone Expert System (CORMIX) model, for carrying out plume assessment and mixing zone analysis during the construction and operation of a typical 1000 MW nuclear power plant at Rooppur in Bangladesh. Assuming similarities in plume characteristics and plume discharge information with Rooppur Power Plant, data of 'Maryland Nuclear Power Plant', USA has been collected and used as CORMIX model inputs following model calibration. Other hydrologic and atmospheric information have been collected from existing literatures for Rooppur site. Sensitivity analysis has been conducted in connection with excess temperature, river width, manning's coefficient, wind speed etc. Thermal Plume generated from the nuclear power plants have a significant effect on water quality, fish production due to high plume discharge, degradation of habitat of aquatic biota due to temperature rise, reduction in the transverse movement of zoo plankton due to large mixing zone covering full river cross section. Lastly the study comes with suggestions regarding the development and provision of a new Mixing Zone Standard for plume management of for nuclear power plants.

Keywords: *Thermal Plume, CORMIX, Mixing Zone, Sensitivity Analysis.*

1 Introduction

Bangladesh would require 35,000MW power production in 2030 (PSMP 2010). To meet up this goal, Bangladesh has been trying to use various fuel sources such as gas, coal, fuel, and other renewable sources so far but more needs to be done (40% population with no electricity and gas).However, with all the initiatives taken already, more still needs to be done as approximately 50% of the country's population still does not have access to electricity. Already the electricity demand for the country outstrips the production, and situations are to further aggravate in future. Considering this, a national level emphasis has been provided on setting up new power plants, promote sustainable energy activities and increase energy efficiency. Rooppur Nuclear Power Plant was first conceived in 1961 and in 2007 the BAEC proposed two 500 MW nuclear reactors for Rooppur by 2015.GoB aims to construct at least one 1,000 MW nuclear power plant by 2018. Cost of Environment also needs to be assessed as it is a burning issue. Any "red category" project requires IEE and EIA for site clearance and environmental clearance respectively (ECR 1997).The objective of the study is to understand and simulate a Hydrodynamic Numerical Plume Model for carrying out plume assessment and mixing zone analysis, as well as investigating the probable environmental consequences which might occur due to the environmental exposure of a typical 1000 MW nuclear power plant (Rooppur) in Bangladesh, and lastly coming up with recommendations to be followed.

2 Study Area

The study area for covers an area within a 10 km radius boundary centering the project site selected for Rooppur Nuclear Power Plant. This includes parts of Ishwardi Upazila under Pabna District, Veramara Upazilla and a small part of Mirpur Upazilla under Kusthia District and also some part of Lalpur Upazilla under Natore District. Figure 1.1 shows the study area of various unions covering a 10-km radius around the project site. The site is situated adjacent to the northern bank of Padma River, 20 km west of Pabna Town, 8 km south of Ishwardi town and 7 km north-east of Veramara town of Kushtia district (Fig. 1). It is located in the Rooppur Union under Ishwardi Upazilia within the Latitudes of 24°03’36”N to 24°04’16”N and Longitudes of 89°02’27”E to 89°03’10”E. The entire complex is completely enclosed, covering an area of about 88 acres and is owned by the Bangladesh Atomic Energy Commission (BAEC).

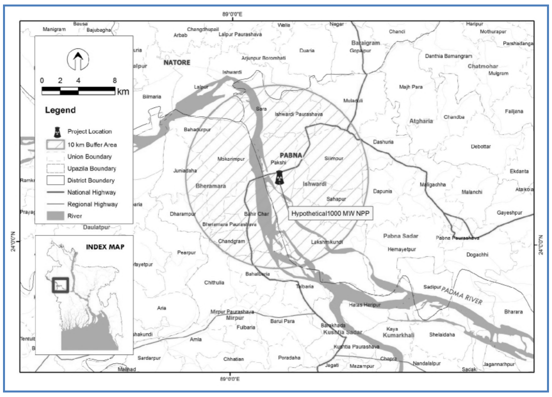

Figure1. Base Map of the Study Area

3 Methodology

The Cornell Mixing Zone Expert System (CORMIX) represents a robust and versatile computerized methodology for predicting both the qualitative features (flow classification) and the quantitative aspects (dilution ratio, plume trajectory) of the hydrodynamic mixing processes resulting from different discharge configurations. The methodology inherently considers the effects of boundary interaction on the mixing process. CORMIX applies to all types of ambient water bodies, including small streams, large rivers, lakes, reservoirs, estuaries, and coastal waters. The methodology has been extensively verified by the developers through comparison of simulation results to available field and laboratory data on mixing processes (Doneker and Jirka 1991; Akar and Jirka 1991; Jones et al. 1996). The system is equally applicable to a wide range of problems from a simple, single, submerged pipe discharge into small streams with rapid cross-sectional mixing to a complicated multiport diffuser installation in deeply stratified coastal waters.In addition, CORMIX is a recommended analysis tool in key guidance documents (EPA 1991a; Jirka 1992) on the permitting of industrial, municipal, thermal, and other point source discharges into receiving waters though the system’s major emphasis is to predict the geometry and dilution characteristics of the initial mixing zone, the system also predicts the behavior of the discharge plume at larger distances. Moreover it is widely used, USEPA approval, specialization and handy characteristics. Nevertheless, this model could be used for different types of flow and discharges. In the study area, the flow is steady and there was no tidal situation in that region and the data was taken in the steady state condition during summer season so CORMIX1 can be used. The study of the certain project site was done by several simulations by CORMIX1.

3.1 Relationship between Actual Hydrodynamic Processes and Mixing Zone

For regulatory purposes, the mixing zone is defined as an allocated impact zone where numeric water quality criteria may be exceeded as long as toxic conditions are prevented. Toxic discharges must comply with additional restrictions to assure rapid mixing and lethality prevention. In practice, a length, area, or a volume may be proposed by the applicant or be determined by the regulator to specify the regulatory mixing zone. Boundary interaction is often defined by plume surface or bottom contact, or in the case of density stratified ambient, formation of a density stratified terminal layer. Lateral boundary interaction can also occur within the mixing zone. When the mixing zone occurs in the near field, the initial discharge momentum, buoyancy and outfall design will dominate the mixing process. Far-field mixing is defined by the presence of an ambient cross flow and is characterized by two distinct physical processes.

3.2 Processing of the Model

CORMIX was chosen to investigate mixing zone design based on the specific requirements of the study. Figure 2 shows a diagram of the modeling process. A number of parameters are required for running the model. After assembling of all the required data into the model, the simulation process has been initiated. It may be mentioned that no mixing zone standard has yet been fixed by the Department of Environment (DoE), Bangladesh. All the ambient data was collected from the location specific of the proposed project site. Some of the data have been assumed depending on the information from literature review and other similar power plant study. Finally the sensitivity was checked though changing different input values. The extent of change in output values also identified through sensitivity analysis.

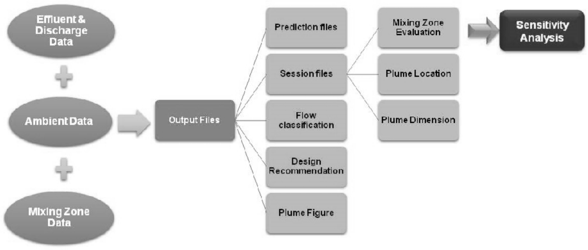

Figure 2. Process of CORMIX Model

This study has been conducted through taking all those data from a typical nuclear power plant, secondary survey result and assuming conditions. The model was simulated by using the following parameters (Table 1) as input variables.

Table 1. Input Parameters in the CORMIX model

Model Parameter	Symbol for CORMIX	Input Values	Remark
	Ambient Data		
Cross section	-	Bounded	Data found
Width	BS (m)	800	
Channel regularity	ICHREG	1	assumed
Ambient flow rate	Q_a (m^3/s)	1581	Low flow at Rooppur site
Average Depth	H_A(m)	7.7m	CORMIX Restriction of limiting average depth ≥ 3 times port diameter
Depth of Discharge	Hd (m)	8.5	
Manning's n	n	0.03	
Wind Velocity	U_{W}(m/s)	3	Assumptions
Ambient Density	ρ_{AS} (Kg/m^3)	1009	
Stratification type	-	Uniform	
	Discharge Data		
Nearest Bank	-	Left	Data found
Distance to the nearest bank	DISTB (m)	400	
Port Diameter	D_o (2.5)	1.5	Assumptions
Port Cross sectional Area	A_o (m^2)	4.9081	Assumptions
Flow discharge	Q_o (m^3/s)	155	Marryland nuclear power plant data
Discharge port height	H_o (m)	1.5	
Vertical Discharge Angle	θ	0	
Horizontal Discharge Angle	σ	0	
Ambient temperature	T_A (^{0}C)	25	Assumption based on local site
Heat loss coefficient		35	Marry land nuclear

Model Parameter	Symbol for CORMIX	Input Values	Remark
			power plant data
Discharge Concentration	$Q_0{}^0C$	8	Assumption
	Mixing Zone Data		
Toxic Effluent	-	No	
Water quality standard specification	-	No	
Regulatory Mixing zone Specification	-	yes	
Region of Interest	XINT (m)	8000	10 times of width of river
Steps of module	XREG	200	assumptions

4 Results and Discussions

There are several scenarios were analyzed in the study. Among them, one of the most influential scenario has been discussed here. The case was taken as summer flow in the Padma river considering river width 800m Ha=7.7m and Hd=8.5m, Qo=155m3/s and other input data are assumed and effluent data are from Maryland power plant nearest distance of port from bank is 400m. The model has provided several information as a result in terms of flow classification, mixing zone analysis, excess temperature variation and sensitivity analysis. The flow was classified as the flow class H5-0(a submerged buoyant water jet) is applied to full water depth according to the CORMIX setup simulation. A submerged buoyant effluent issues horizontally or near horizontally from the discharge port. From the simulation, a session file was given which showed the mixing zone evaluation indicates that origin of the port is located at the bottom below the port center:400m from the left bank. The flow is the positively buoyant and tends to rise towards the surface. No toxic dilution zone was found.

4.1 Mixing Zone Analysis

The near field region (NFR) is the strong zone of initial mixing and it has no regulatory implication. The location of NFR is at 3636.6m which is within the assumed regulatory mixing zone. For RMZ, plume condition at the boundary of the specified the plume location was 1038m. Cumulative travel time of the plume was 27 min which was lower than that of NFR. It indicates that RMZ was within the NFR. RMZ analysis indicates that the RMZ specification occurs before the NFR has been completed.

4.2 Temperature variation and Dilution variation with distance

The simulation also provides the temperature variation as per dilution of the plume with the distance. During the discharge of plume, the excess temperature in the initial stage, is high and corresponding dilution is low (Figure 3 and 4).From the curve (Figure-3) we see that the value of excess temperature is 0.34^0C at the RMZ specified boundary of 1038m. The excess temperature is 0.1835^0C at the distance of 3636m for the NFZ zone. The excess temperature consecutively decreases with distance and disperses up to 8000m.

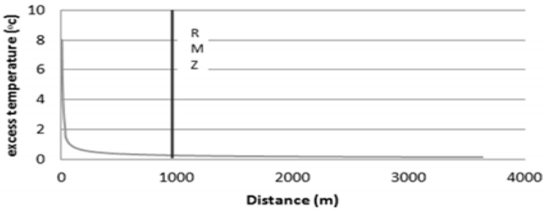

Figure 3. Excess temperature (vs) downstream distance curve

Figure 4 shows the curve of dilution variation against distance, where dilution increases with the downstream distance. At the RMZ location, the dilution is 23.2 and at the NFR location, the value of dilution is 43.6.The initial concentration is very high as because dilution is very low while the concentration decreases with respect of distance and dilution increase significantly**.** There exists inverse relationship in between excess temperature and dilution.

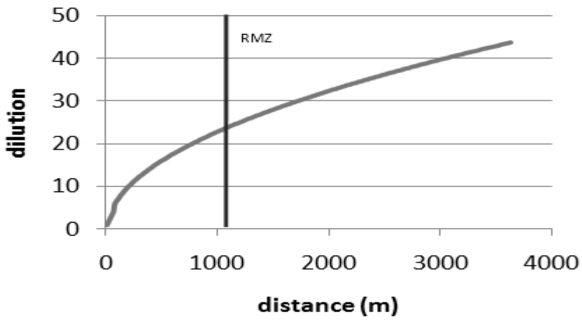

Figure 4. Dilution (vs) downstream distance curve

The model has shown a 3-D Corvue diagram of plume dispersion.

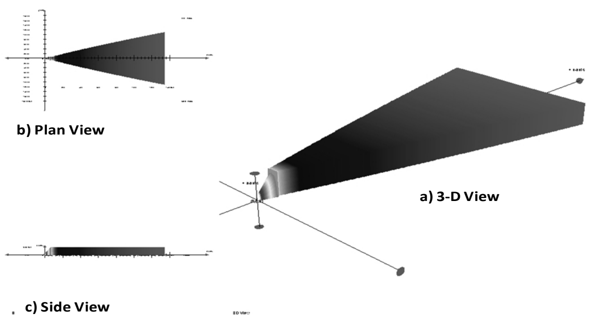

Figure 5. Plume Dispersion a) 3-D View b) Plan View c) Side view

4.3 Sensitivity Analysis

The main purpose of sensitivity analysis of the model was to make a comparative analysis the relative model coefficients to predict the concentrations by using varying one parameter of interest at a time while keeping other parameters unchanged. The effect of this change is studied to determine the significance of parametric dependence of the model. Sensitivity analysis is usually significant for far field region. In this study it shows that the model sensitivity marginally varies with changes in effluent excess temperature and distance variation within the NFR. The parameters are Manning's roughness coefficient, wind speed, heat loss coefficient, river discharge and excess temperature concentrations and river cross-section for the simulation which were used for simulation in the case study. These parameters were chosen to be tested because these parameters were assumed or otherwise estimated for the simulation and may be subjected to fluctuations within the day or the month. Sensitivity analysis was based on the centerline plume temperature variation. In Figure 6, the discharge temperature excess might have some pronounced variations in the near-field but as the plume dilution increases with increased mixing along the distance, the initial excess temperature has less pronounced effect. The model is sensitive to smaller channel width with greater depth whereas it is insensitive to greater channel width with a smaller depth. The effect of ambient discharge is more important in the far-field region rather than in the near-field.

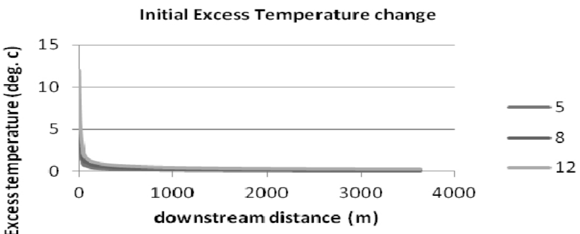

Figure 6. Sensitivity Analysis

5 Probable Impacts on Environment:

The study observed an inverse relation between effluent excess temperature and distance (excess temperature decreases with distance). Sudden drop in temperature was found within the internationally acclaimed 100 meter regulation zone. This indicates a relatively higher heat absorption rate of surrounding water. Thermal Plume generated from the nuclear power plants have a significant effect on water quality The study identifies effects on water quality, fish production due to high plume discharge, degradation of habitat of aquatic biota due to temperature rise, reduction in the transverse movement of zoo plankton due to large mixing zone covering full river cross section. Excess temperature also affects other sensitive water quality parameters i.e. DO, pH, EC and TDS. This would impact the habitat suitability, species growth and migration etc.

6 Limitation of the Study

The numerical model used in the study has been developed based on assumed cases, data and information and values, as no detail feasibility investigations were available. In-situ information could not be collected due to time constraints, and the model inputs were based on secondary data. Furthermore, the assessment of environmental consequences was fully probabilistic and idea based, without any detail field investigation.

7 Conclusion and Recommendations

Considering the development potential of nuclear power plants in Bangladesh as well as the environmental consequence' hot spots, it is extremely important to carry out comprehensive analysis on plume assessment and its impacts on the surroundings. This study made an attempt to investigate the specifications of thermal plumes of nuclear power plants, considering a submerged single port hypothetical power plant located in the RNPP site, and therefore foreseeing the environmental effects of thermal plume distribution. This study therefore identifies the following hot-spots where national level regulations are needed.

A Framework should be developed with specifications of regulatory mixing zone for nuclear power plants in Bangladesh. Water quality standard values should be established for RMZs. A comprehensive policy may be developed, connecting renewable energy planning and ecosystem conservation and management. Existing regulations for plume discharge temperature as per ECR 1997 should further be reviewed and updated, and new regulations should be provided for plume concentration. Excess temperature of thermal plume should undergo controlled discharge, following the standard levels set by IFC2007.Technological advancements may be introduced (upgraded cooling towers; increase in diffuser distance; reduced temperature, increase jet momentum etc.).More studies should be carried out regarding design, construction, operation and environmental implications of nuclear power plants.

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