MODELLING OF DIFFUSION AND DISPERSION OF HOT WATER DISCHARGE VIS-A-VIS HYDROTHERMAL-INFORMATICS

Manivanan, R. *   Singh, C.B. †

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Abstract: Since the modelling of diffusion and dispersion of hot water discharge problems should include the post-thermal behavior affecting the environment, there is an urgent need in our country to develop and formulate "HYDROTHERMAL-INFORMATICS" in order to maintain thermal pollution within the permissible limits prescribed by the Indian Standards. So far, it is not clear how far and how much (level and degree) of aquatic life (flora and fauna) of the water body is affected in any of real situations under operational condition in our country. This is illustrated using data from periodic field studies during operational condition in case of Biscayne Bay, USA. Keeping in view the periodic data on post thermal discharges in India, the mixing zone concept and Indian Standards need to be re-examined A probabilistic approach for defining the mixing zone using world bank standard may also require further attention in defining mixing concept in Indian standard. Based on pre and post corroborative field studies, an adequate hydrothermal-informatics could be formulated and developed. In this paper, the authors have emphasized the need to synthesize the analytical work and field data related to thermal dispersion in order to re-examine the thermal standards at outfall related to the mixing zone and permissible temperature differences and modify, if necessary.

Key words: Modelling, Diffusion, Dispersion, Water Discharge, Hydrothermal.

*PhD, Assistant Research at Central Water and Power Research Station at Khadakwasla (Pune MH, India) e-mail: vananrmani@rediffmail.com

†PhD, Joint Director Fellow at Indian Society for Hydraulics (Pune MH, India)

1 Introduction

Spreading of a pollutant introduced in a water body and changes which occur in its distribution and concentration include diffusion and dispersion (mixing). This dispersion is greater than hundred times larger than the turbulent diffusion. Mathematical modelling of hot water discharge is just one part of the area of technology for which the name Hydrothermal-informatics is suggested. Hydroinformatics has to do with the whole gamut of information technology in hydraulics and water resources, whereas the hydrothermal-informatics includes Hydroinformatics including information on all the aspects of thermal pollution and related socio-economic and legal aspects. Hydrothermal-informatics includes both the researches in theory of thermal dispersion as well as practical information of relevance to hydraulic and environment engineering in particular and the society in general. The basic premise in hydroinformatics is that one cannot any more carry out hydraulic research without simultaneously researching how this research work is to be applied in practice. By the way the researching the mode of application, one can properly identify the real need of hydraulic research in practical aspects.

When hydroinformatics was first introduced at the end of the 1980s, it was still centered around the use of existing numerical models and modelling systems. Hydroinformatics then built up its system around these models to provide such products and services as decision support systems, diagnostic systems, forecasting systems,real time control system and many others. From the early 1990s onwards however, the focus has shifted strongly towards examining and selecting means of encapsulating knowledge, in conformity with the nature and socio-economic requirements of the applications. The participatory approach adapted by the Chilika development Authority for restoration of biodiversity of the lake has been shown in the form of hydroinformatics in Figure 1 and Figure 2 of Bendre [4]. Singh [21] reveals that hydroquality is a new concept which is an extension of water quality modeling.

2 Modelling of Hot Water Discharge

The region of water body which undergoes changes in temperature due to heated water discharge is termed as the thermal plume. This begins at the hot water outlet and extends in horizontal and vertical directions. The behavior of thermal plume is influenced by many parameters such as the flow rate and temperature difference at the outlet and its characteristics, flow dynamics of receiving water body, relative locations of intake and outfall, withdrawal velocity, type of structure and the meteorological conditions. The thermal plume can be broadly divided into two zones: namely near field and far field. Near field is the zone adjacent to the discharge point.

Near field dilution and initial spread of buoyancy of thermal discharges can be determined using a hydraulic scale model for any type of outlet. Far field models need scale distortion for several reasons. In order to guarantee the similarity of turbulence, the vertical scale must exceed a certain value. Therefore, undistorted models would lead to large horizontal model dimensions and flow rates. Secondly, correct reproduction of heat loss through the water surface also requires scale distortion. For this reason near field modelling which requires undistorted scale must be done separately. The near field results are then transferred to the far field mathematical model as a boundary condition. The full 3-D, semi 3-D, 2-D vertically integrated, 2-D laterally averaged and 1-D advection dispersion temperature models are available in literature Singh [21], Sivighia & Toro [20] and Chao *et al.* [7] which can be used depending on the nature of the problem and flow pattern in real situations. If the water movement is mainly 2-D horizontal and if density current is of minor importance, a semi 3-D approach can be applied. The water movement is computed on a depth integrated basis. From the output fields a 3-D flow field is computed assuming logarithmic velocity profiles in the vertical. These data are put into the 3-D temperature model which gives the temperature distribution pattern. In general, mathematical modelling of diffusion and dispersion processes involves solution of continuity and momentum equations along with the equations of conservation of heat.

3 Near Field and Far Models

Although the near field model may realistically simulate flume behavior in the vicinity of the outfall, they are not capable of accurately simulate effluent transport in area significantly away from immediate vicinity of the outfall. The far field model is required to realistically predict the transport and fate of effluent in those areas. In a paper by Blumberg *et al.* [5] the authors have attempted to reproduce the near field behavior by a far field model in case of hydrodynamic and water quality models for Masschusetts Bay, USA. The near field behavior of an outfall plume has been simulated by using various near field plume model for example CORMIX and many other models as given in Blumberg *et al.* [5]. Far field models have been reported by many authors including Blumberg *et al.* [5], Manivanan *et al.* [14] and Patil *et al.* [18].

4 Need for Post Thermal Discharge Data (Biscayne Bay, USA)

The CWPRS Khadakwasla has been involved in conducting physical and mathematical model studies along with field data collection of thermal power plant. The periodic degradation of aquatic life of the water body and the extent of mixing zone are presented in Table 1. A close study of Table 1 indicates that the aquatic life in the vicinity of outfall (within 0.84 Km^2) was destroyed after a period of fourteen months. This emphasizes the need for similar studies for the existing thermal power plant. Laboratory research for the effect of thermal discharge on individual aquatic environment will be highly beneficial and could be a supplement to field studies.

5 Post Thermal Discharge in Arabian Gulf

In Kolluru *et al.* [13], RasGas operates a LNG facility on the north east coast of Qatar, north of Doha. RasGas discharge cooling water into Arabian sea resulting maximum temperature rise of 10 ^{o}C with minimum jet momentum. The hot water thermal plumes show that the plume radial dimension are much larger than the 100 m radius limit proposed by the World Bank [22], but the nixing zone dimensions can be altered or redefined based on its by impact on local biological conditions as proposed by the World Bank. The benthic data that has been collected in vicinity of the RasGas site allow the definition of the mixing zone based on biological impacts rather than arbitrary dimension. World Bank standards allow site by site determination of the mixing zone based on local biological community. Biological survey in the immediate vicinity of the thermal discharge show few species and numbers where as bottom organism further away from the discharge are more abundant.

Table 1: Post Thermal Discharge Data of Biscayne Bay, USA (2.080 MW, temperature rid 7.9 ^{o}C)

Period after operation	**Thermal Effect on Aquatic Life**
Three months	8,000-12,000 m^2 area of barren sediment was found off the month of discharge canal Turtle grass was completely gone in this area (8,000-12,000 m^2) These area are were covered by irregular mats of blue green microalgae
Six and half month	Barren sediment area were expanded to 400,000 m^2 (0.40 Km^2) Noticeable damage to benthos (grass in particular) was apparent over an additional are of 800,000 m^2 (0.8 Km^2)
13 months	Regrowth in turtle grass occured over much of 800,000 m^2 (0.8 Km^2) area that had been adversely affected. However an area of 0.4 Km^2 near mouth of discharge canal still remained devoid of usual benthic biota.
First week of 13 months	Further deterioration of benthos becomes apparent. The coral colonies within 350-550 m of the outfall died and some dead corals were found as much as 750 m from the outfall.
Third week of 14 months	The turtle grass at 550 m from the outfall was losing its green colour to brown and some of turtle grass beginning to loose colour and vigour at distance up to 900 m from outfall. At 750 m from the outfall, 50-70% of corals were dead.
Fourth week of 14 months	Thousand of dead fishes were found within 900 m from outfall - A complete kill of aquatic organism occurred over an area of 0.84 Km^2 - Bottom was littered with dead plants and animals in addition to wilted and browned algae and covered a total area of 2.7 Km^2.
During 16 months	Increase in temperature of bay water at least 2.2 ^{o}C over an area of 2.5 Km^2 and near mouth of discharge canal temperature was about 4.4 ^{o}C.

Table 2: Summary of Effluent Temperature Standards

Country	Standard
World Bank Standard	Temperature increase of not more than 3 ^{o}C 100 m from the point of discharge (where the zone is not defined) Variations in dimension 95% of the plant operating off the month
USA	Maximum temperature: Depending on the organisms living in a particular ecosystem Max. Temperature increment: in streams 2.8 ^{o}C, in lakes (epilimnion) 1.7 ^{o}C in estuaries and coastal waters summer 0.8 ^{o}C and winter 2.2 ^{o}C Mixing zone defined as the area in which the temperature is higher r than the temperature permitted under the receiving water standards For estuaries and streams it is recommended that adequate passageways will be provided to permit movement of drift around potentially harmful mixing zone. Passageways should be preferably 75% of the cross-sectional area and/or volume flow. Mixing should be accomplished as quickly as possible through use of devices which ensure that the waste is mixed with allocated dilution water in smallest possible area
Russia	Temperature rise of rivers and lakes: Summer: 3 ^{o}C, Winter 5 ^{o}C Complete mixing of the heated effluents must take place within 500 m of the discharge point
Germany	Max temp at the end of condenser discharge canal 30 ^{o}C Max temp in surface water after mixing 28 ^{o}C Max temp increment in surface water after mixing 3 ^{o}C DO should not fall below 5 mg/l
Switzerland	Max temp at the end of condenser discharge canal 30^{o}C Max temp in surface water after mixing 25 ^{o}C Max temp increment in surface water after mixing 3 ^{o}C
India	Condenser Cooling Waters (Once through cooling system) Temperature Not more than 5 ^{o}C higher than the intake water temperature

6 Regulation Acts/Standards in USA, Russia, Germany, Switzerland & India Along With World Bank Standard

Table 2 presents the summaries of effluent temperature standards for World Bank, USA, Russia, Germany, Switzerland and India. This Table is self-explanatory and is not discussed here. The environment (Protection) Act, (Ministry of Environmental and Forest, 1986) says Temperature rise of condenser cooling water discharge from thermal power station to the receiving body should not be more than 5 ^{o}C above the ambient temperature whereas in India the temperature rise through condenser is found to vary from 7 to 10 ^{o}C. The Bureau of Indian Standards vide IS:2490 (Part I) 1981 states that Industrial effluents discharged into inland surface waters shall not exceed 400 C in any section of the stream within 15 m downstream from the effluent outlet, while discharging into public sewer or into marine coastal areas the limit is 45 ^{o}C (including ambient) at the point of discharge. Maharashtra Pollution Control Board Act states Temperature in the receiving water at 15 m from the discharge point shall not be more than 5 ^{o}C above ambient. This 15 m and 5 ^{o}C need to be carefully examined in Indian scenario as Table 2 shows that the thousand of fish were found dead with 900 m of outfall. Table 2 shows that the USA standards regarding permissible temperature differences and mixing zone length are more stringent and hence conducive to preservation of aquatic life. This aspect of relating temperature and mixing zone length to the preservation of aquatic life need to be carefully studied based on analysis of field data in the Indian context, and necessary modifications in the standards introduced. The probabilistic approach using World Bank standard [22] was described in Kolluru *et al.* [13] and Manivanan *et al.* [15].

7 Monitoring Post Thermal Discharge Data on Environmental Parameters in India for Reexamination of Indian Standard

In Indian standard as described in Table 2 along with standards of World Bank, USA, Russia, Germany, Switzerland are required to be re examined after corroborative field studies in respect of pre and post thermal discharge data affecting in totality in physical, chemical and biological parameters. Ghosh *et al.* [10] described the detailed monitoring of physical, chemical and biological characteristics which includes;

1. Abiotic characteristics (DO, BOD, COD, alkalinity, calcium, magnesium, potassium, sodium, nutrients like nitrates, phosphates, etc along with physical parameters like color, temperature, odor, pH, and conductivity).
2. Biotic characteristics (Phytoplankton, zooplankton, bacteriological study on total coliforms and facial coliform).

The post thermal discharge data collected as given in Table 2 shows how at an interval of 3, 6, 13, 14, 16 months. Aquatic life of sea is being damaged and recouped in Biscayne Bay, USA. No monitoring of environmental parameters for this case study has been done. The post thermal discharge data collected into Arabian gulf in the vicinity of outfall discharge as given in Kolluru *et al.* [13] is very meager and benthic data that have been collected in the vicinity of the RasGas site allow the definition of the mixing zone based on biological impact rather than arbitrary dimension.

The DO, TC, AN and pH have been collected and monitored as given in Gupta *et al.* [11]. The phytoplankton species assemblage and their relationship to hydrographic factors in the vicinity of old Mangalore port at coastal Arabian sea have been collected and monitored in Harnstorm *et al.* [12]. APHA [2] [3] literature are examination of measurement of environmental parameters.

Accordingly it is suggested that the executive authority concerned with operation of thermal discharge at different locations of east and west coast of India may decide in collecting and monitoring post thermal discharge data on environmental parameters affecting the aquatic life of sea and to reexamining the Indian standard in the light of the most important changes in the biotic and abiotic characteristics of post thermal discharge data.

8 Conclusion

In addition to conducting physical and mathematical model studies of thermal discharges in the water body, it is essential that data concerning observed temperature differences between outfall and intake point, length of near-field zone and conditions of flora and fauna and BOD be collected in order to examine the permissible limit prescribed by respective Standards. Such study will help in improving the design methodology and environmental quality, thereby fulfilling the social obligation. The rise of 5 ^{o}C or so at outlet be clearly defined in terms of mixing zone taking into account of the diversity of ecosystem of hydrological and seasonal variation of cooling water sources namely (i) large lakes including impoundment (ii) Coastal marine water body (iii) rivers and streams and (iv) estuaries, while keeping in view the standards and field data collected of other countries listed in Tables 1 & 2. Thus there is a need to develop and formulate hydrothermal informatics, which includes all the information related to hydraulics and water resources, thermal pollution in respect of biotic and abiotic characteristics, socio-economic issue and legal implications and post thermal discharge data affecting flora and fauna are required to be collected in India for further reexamining mixing zone concept and Indian standards.

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