Analysis of Warm Water Discharged By Nuclear Power Plants

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Abstract

The circulation and hydrographic variations in inner shelf of a semi-enclosed bay adjacent to a nuclear power plant of the southernmost Taiwan were analyzed. The dominant tide in the bay is the mixture of diurnal and semidiurnal components. Currents are dominated due to tidal force which flows southwestward during flood and towards northeastward during ebb. Amplitudes of tidal currents range from 0.2 - 0.4 m/s. A persistent southwestward subtidal flow is present with a mean velocity of 0.15 m/s. The upwelled cold deep water in central bay can intrude to the inner reach near the outlet, causing sudden temperature drop. Thermal discharge from the power plant creates a buoyant plume near the sea surface, which is the most prominent feature in receiving water around the outlet. The thermal plume is 5 to 7 m thick just outside the outlet and shoals to less than 1 m near sea surface as it disperses seaward. The thermal plume is usually restricted to within a 1 km radius around outlet; tidal currents substantially modulated its shape, stretching out as a tongue towards the southwest during flood and fanning it out towards the northeast during ebb. Thermal discharge does not recirculate back to the intake.

Keywords: *nuclear power plant, thermal plume, tidal current.*

1. Introduction

Heated water released from nuclear power stations at coastal regions raises significant concerns about the conservation of marine environments. The heated water is pumped into the coastal water through an open channel, possibly forming the thermal plume and causing modulations of coastal circulation through baroclinic effect [1]. The discharge might be thermal pollutant endangering the ecosystem. Monitoring the thermal effluents and the associated hydrographic variations in coastal water close to nuclear power plant is therefore crucial to understanding the marine environment and assessing their effect on the ecosystem.

The nuclear power plant of the Taiwan Power Company (Taipower) was constructed at the southernmost coast of Taiwan. Located at west coast of the semi- enclosed Nan Wan Bay, the power plant pumps in coastal water to cool the generators and releases the heated water back to the surrounding sea. The bay is open southward to the Luzon Strait that links the South China Sea and western Pacific Ocean. The exchange of the Kuroshio water, South China Sea water and local coastal water causes the complex seasonal variation of water masses in the bay. The swift tidal currents together with intermittent internal waves causing upwelling of cold bottom water in the central bay that might intrude towards the shallow inner shelf causing sudden temperature drop. To evaluate the effect of human activity on the marine environment, Taipower commissioned research institutes and university, including Taiwan's Academia Sinica, National Taiwan University & National Sun Yat-Sen University, to monitor the variations in circulation, hydrography, water quality, ecology and fishery economy in receiving waters of the power plant. This work focuses only on analyzing the properties of physical hydrography, including tides, currents and temperature variations.

Early investigations confirmed that tidal currents off the outlet generally flow along the coast, southwestward during flood and towards northeastward during ebb. Amplitudes of tidal currents range from 0.03 to 0.3 m/s near the outlet. The subtidal flow towards southwestward with a velocity in range 0.1-0.2 m/s. Tides in the coastal region are predominantly diurnal. The diurnal tides frequently mask the semidiurnal tides, leading to spring & neap tides that are unrelated to semidiurnal tides. Spring & neap tides in the bay are therefore defined respectively by periods of high and low tidal ranges in a fortnightly cycle. The mean tidal range is 1.8 m during spring and 0.5 m during neap tide. Carried by surface current, drifter released at outlet drifts southwestward hugging the Mou - Bi-Tou coast during flood and predominantly towards the east to northeast during ebb. Hydraulics Laboratory monitored the thermal effect and concluded that warmer and lighter discharge forms a thermal plume floating over surface layer (depth < 3 m) after departing from outlet. The shape of the thermal plume is controlled by tidal streams, extending southward during flood but dispersing towards the east during ebb. The thermal plume is generally restricted to a 1 km radius around the outlet. The sea surface temperature (at 1 m depth) decreases by about 4 to 8°C from the outlet to the perimeter of the thermal plume. Su concluded that the thermal discharge does not affect intake of cooling water.

The historical observation provides information about essential hydrographic features for coastal waters adjacent to the power plant to lowest order. Researchers have carried out intensive investigations to improve our understanding of the thermal effluents and the background environment.

2. Literature Review

The project aims at finding the thermal plume formation by considering different environments with the help of CFD analysis. In this project an attempt has been made to study the variations types of intake and outfall and hence the thermal plume formation at different water bodies. I observed various literature materials for the study of my project. During literature review I found some of the similar examples in those literature materials quite similar to the analysis I did.

One of the paper was on location and design of cooling water intake and outlet structures for power plants in Germany's coastal area [9]. Planning of cooling water structure for coal fired power plant is actually experience a renaissance in Germany. The locations along the German shoreline are beneficial for two reasons. Firstly, economic transportation of coal to the site can be guaranteed from sea. Secondly, the often applied once through cooling technology requires the withdrawal of large quantities of cooling water. The paper summarizes the concepts for location and design of the intake and outlet structures of a cooling water system and presents a project example carried out for a site at the Norderelbe in Hamburg.

Location of cooling water structures in tidal water bodies, Design of cooling water structures, Intake structures, Pumping stations, Cooling water pipes, Outlet structures, Environmental aspects etc [6].

2. Observations

Currents at the location are measured with a Doppler current meter. The mooring site was about 200 m southeast of outlet, where the depth of water is 28 m. The current meter installed at 6 m below sea surface and measured current speed & direction continuously. The hourly velocity data were analyzed by using traditional statistics, the Fourier transform and the harmonic analysis. The Morlet wavelet transform was adopted for localizing and quantifying the variability of current simultaneously in both frequency & time domains. Relevant sea level fluctuations at tide-gauge station midway between the inlet and the outlet and winds at weather station north of the power plant were collected from the Taiwan Central Weather Bureau. The hydrographic variations were measured with a portable CTD (Conductivity-Temperature- Depth sensors). Each survey consisted of 25 casts within four hours during a tidal phase. Since four-hour duration is not a negligible fraction of a tidal period, the hydrographic distributions derived from the CTD observations are only quasi-synoptic. By comparing, the spatial variation of salinity is smaller than that of temperature during a survey period and therefore the study only presents temperature variations. To better resolve the thermal plume, intensive CTD surveys of 43 stations in fan shaped area of 1 km radius around the outlet were conducted during flood and ebb. The thermo-drogue, with a drag vane at a depth of 4 m, was released at outlet mouth at different tidal stages and recorded temperatures at depth 1 m along with drifting trajectory. All measurements were conducted routinely.

3. Objective

The objective of this study is analyzing the observational results, especially those that are related to thermal plume formation area. Observational results will hopefully lead to future numerical model development. The location, design, construction and capacity of cooling water intake structures at new power plants reflect the best technology available to minimize adverse environmental impact and protect fish, shellfish and other forms of aquatic life from being killed or injured.

4. CFD Procedure

Flow Science, Inc. is developer of software for computational fluid dynamics, also known as CFD, a branch of fluid mechanics which uses numerical methods & algorithms to solve and analyze problems that involve fluid flows. The company's products named FLOW-3D, CFD software analyzing various physical flow processes; FLOW-3D/MP, a CFD high performance computing product known as FLOW-3D Cast, a software product for casting users; and FLOW-3D ThermoSET, a thermosetting resin CFD modeling software is used for products using thermosetting resins. The FLOW-3D software uses a fractional areas/volumes approach is known as FAVOR for defining problem geometry and a free-gridding technique for mesh generation [12].

5. Temperature Variations

The sudden temperature drop is a prominent feature of the bay, receiving extensive studies in recent decades. Lee et al. linked it to the tidally induced upwelling which occurs daily and preferably during spring tides. According to their results, the cold water intrusion usually begins after lower low tide and peaks before lower high tide. The temperature subsequently rises more slowly. This study investigates the reach of upwelled cold water close to the outlet.

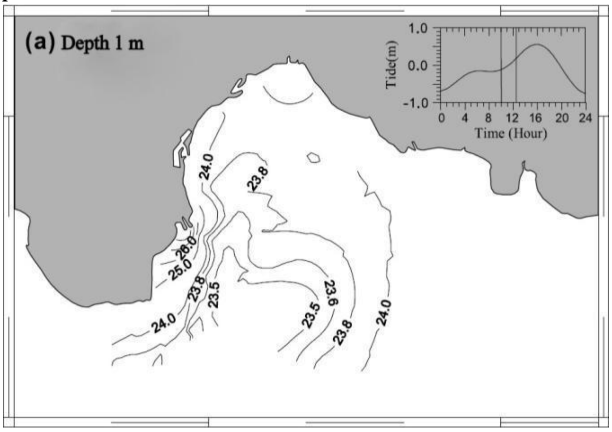

Fig 1 (a) Temperature distribution at depth 1 m [11]

Figures show horizontal temperature distributions at depths 1 m and 30 m at different tidal stages in a larger area. Fig. 1 (a) reveals that during flood, the majority of the thermal effluents (> 26°C) are confined in the left side of the outlet hugging the east coast of the Mou-Bi-Tou, and do not reach the region off the inlet.

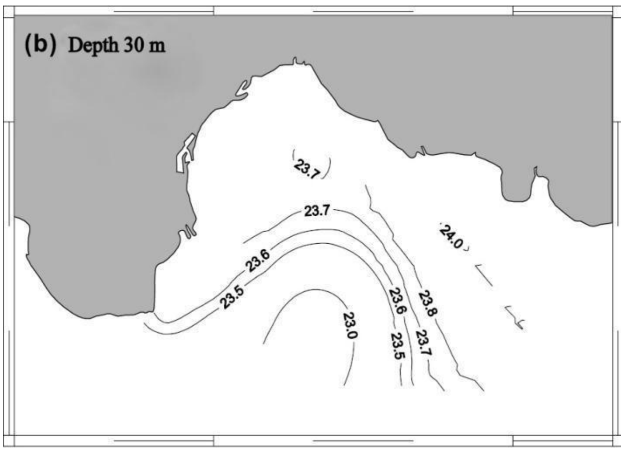

Fig 1 (b) Temperature distribution at depth 30 m [11]

A cold water zone (< 23.5°C) is located in the surface layer southeast of the outlet. In the central bay, the temperature remains at 24°C and varies little. Fig. 1(b) shows a colder zone (< 23°C) at depth 30 m.

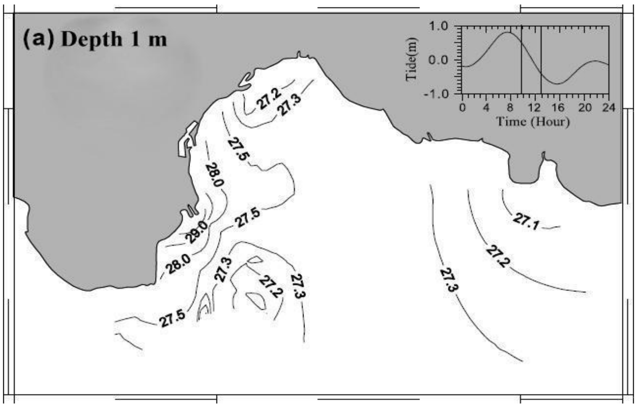

Fig 2 (a) Temperature distribution at depth 1 m [11]

The cold surface water could conceivably come from the upwelled cold bottom water.

Fig. 2 (a) indicates that temperature distributions during ebb are different from those during flood. Fig. 2(a) shows that thermal effluents (> 28°C) disperse as a fan shape around the outlet. A cold water zone (< 27.3°C) still exists southeast of the Mou-Bi- Tou.

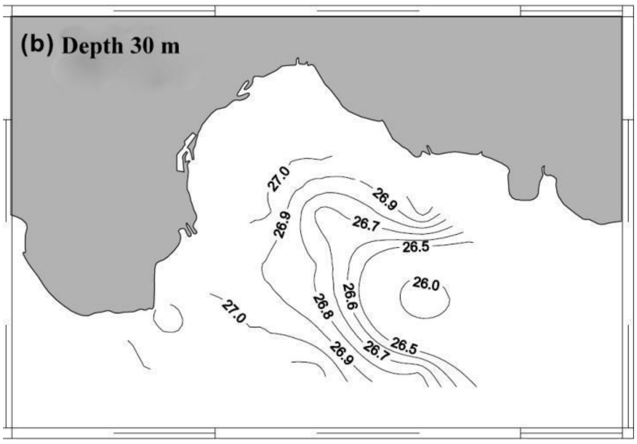

Fig 2 (b) Temperature distribution at depth 30 m [11]

Away from the shallow inner shelf, there is no appreciable temperature distribution pattern at the surface layer. At a depth of 30 m, the cold water zone shifts eastward during the ebb Fig. 2(b). The nearly isolated cold water zone can normally be observed extending from deep to surface layers despite the tidal phase variation. Regardless of the complexity of the sudden temperature drop, tidally-induced upwelling probably causes the cold anomaly.

6. Discussions

Sea level, current, temperature and drifter trajectory measurements were systematically conducted to better resolve spatial and temporal variations of the hydrography in the coastal sea close to the third nuclear power plant of Taipower. The dominant tides are a mixture of diurnal and semidiurnal tides, with the former slightly larger than the latter. Results derived from current measurements suggest that the nearshore currents are dominated by tidal forcing, flowing southwestward during flood and northeastward during ebb. The amplitudes of tidal currents range from 0.2 to 0.4 m/s. The compound tides and overtides produced high frequency fluctuations occupy a sizable fraction of tidal currents in the shallow shelf of the embayment. The southwestward-flowing subtidal current is relatively weak (approximately 0.15 m/s) and is probably independent of seasonal variation. The long shore currents can be estimated simply by using real time sea level observations [η (t)] through the equation:

$$v(t) = 0.1830 \times \eta(t-1) + 0.1858 \times \eta(t-4) - 0.3371$$

The root-mean-squared error of the estimation is 0.18 m/s. The sudden temperature drops are observed as close as 200 m from the outlet. Discharge of heated cooling water from the power plant produces a buoyant thermal plume, forming the most striking hydrographic feature in the coastal ocean. The horizontal plume shape, stretching 600 m southwestward along the coast during flood and becoming a small bulge-like shape expanding towards northeast during ebb, is mostly dictated by the coastal currents. The thermal discharge does not recirculate back to the inlet. The intensive CTD surveys and drogue trajectory observations both show that the thermal effluents have a spatial temperature drop rate of about -0.008 to -0.01°C/m at 500-800 m away from the outlet.

This work uses intensive observations to describe spatial and temporal variations of currents and hydrography in the coastal ocean adjacent to the nuclear power plant.

7. Conclusion

The thermal plume occupies 5-7 m thick in the surface layer right after discharge, becomes thinner when it is dispersed farther seaward, and is essentially restricted within about 1km from the outlet. Further work is required to develop a high-resolution three-dimensional numerical model to simulate the inner shelf circulation and the dispersion of the thermal effluents.

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