3D Physical Modelling of Thermal Discharge: A Case Study

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ABSTRACT


Heat transfer from an industrial area cooling water with an open channel discharge in a sea was studied in laboratory hydraulic model. Temperature variation was measured in the basin at various locations and dispersion of the heat in the sea was observed with several tidal cycles. Experiments were indicated effect of the heat variation at the control point (600 m far from source point that given by the authority) less then 1 °C by every flow condition. Path of the heat distribution had same pattern with tidal current.

ADITIONAL INDEX WORDS: Heat dissipation, coastal thermal pollution, tidal mixing.

INTRODUCTION

Being one of the important types of water pollution thermal discharges cause significant changes on the marine environment. The main origin of thermal discharge is the cooling water of power plants. Usually this water is supplied from a near water body by an intake structure and discharged back afterwards through an outfall structure. The adverse effects of thermal discharges on marine environment are certain. It not only affects the metabolic activities of marine life, but also decreases oxygen solubility (ÖZTÜRK et al., 1995). However, discharging high temperature water to seas or oceans is most of the time inevitable. The important point is implementing thermal discharge structures accordingly to minimize these adverse effects. This can only be done with testing by means of numerical and/or physical models.

In the literature studies made with numerical models are mostly available, because most of the time numerical models are less time consuming and cheaper compared to the physical models (SUH, 2001). In addition to this it is much difficult to control the boundary conditions in physical models as far as temperature is concerned. Also tidal effect is a significant parameter in this case, which is also one of the most important components of numerical modelling as well as physical modelling (DAVIES et al., 1997).

Briefly the temperature must be reduced as soon as possible after the discharge not to cause any damage on the marine ecosystem. The main way of temperature reduction is mixing and increasing the aeration surface. If rivers or water bodies under effect of currents are concerned, the mixing process can be better satisfied with a hydraulic jump (TOWNSEND et al., 1975).

In this study performing the physical model tests of a thermal discharge system of the power plant of an industrial area in Sohar, Emirate of Oman, is focused. Tests conducted to confirm two main issues; first the proper dispersion of wasted cooling water and the second prevention of a feedback mechanism between the intake and outfall structures which may cause reheating of water.

Usually numerical models for heat dispersion (transport) are based on the following equations:

\[
\frac{\partial T}{\partial t} + u \cdot \frac{\partial T}{\partial x} = K \frac{\partial^2 T}{\partial x^2} + \gamma T + S \tag{1}
\]

in which \( u \) represents an apparent velocity,

\[
u_i = u_i - \frac{1}{h} \frac{\partial h}{\partial x} \tag{2}
\]

here, \( T \) is the temperature of heated water, \( K \) is dispersion coefficients, \( \gamma \) is heat loss coefficient at surface and \( S \) means sink or source of heat.

In numerical models, this equation is solved together with the general governing equations of numerical hydrodynamic simulations.

EXPERIMENTAL SETUP

Main investigation in the model study was determination of heat distribution and diffusion characteristics around the discharge and intake points. The method used in this study was implementing a 3D physical model of the coastal area in a laboratory basin with dimensions of 22 m x 26 m x 1 m. The model had a distorted geometric scale, 1/60 in horizontal (\( L_o \) and \( L_r \)) and 1/25 in vertical (\( L_z \)). Froude similarity was used when setting the model as inertia forces are much dominant than the viscous forces.

The model boundary included the intake and outfall structure of the thermal discharges; nearly 1400 m long shoreline (1000 m to the water intake axis protected by breakwater and 200 m to the right side of the discharge channel), and vertical limits of the model bathymetry was +4.5 m to -4 m. The walls and the bottom of the model basin were made of concrete and bricks. The thermal discharge was reached to the coast by an open channel and the outfall structure was a conic shaped channel mouth. The design discharge was 334 000 m³/h with an excess temperature of 8 °C with respect to the mean sea temperature, and a conic shaped riprap apron (about 600 m length) with rock armouring units was placed to protect the sea bottom (KABDASLI, 2003a). All measurements are at prototype scale. Also there were breakwater structures on both sides of the intake to reduce any feedback because of the long shore drift. Four pumps are placed in the model (Figure 1) for generation of the tidal conditions.

Tidal velocity was controlled by these pumps for each tidal period. Guide walls and a mobile pump (Pump 3 in Figure 1) were used to create the direction of the tidal current. Tidal direction and current velocity was observed by a 3D Acoustic Doppler Velocimeter device (ADV), which was placed at the offshore edge of the stone-protected area (Figure 1) (KABDASLI, 2003b). The velocity and direction data for the tidal current, which based on the in situ measurements, were given by the third parties; the mean tidal current velocity was given as 1.5 m/s (NNW at the edge of the noncomplete path is traced on Figure 1).

Only tidal effects were included in the model; neither wave nor wind effects were included, as their effects make mixing
process easier as far as the cooling is concerned. The representation of passive effects is always difficult in a physical model study; besides, a conservative approach was preferred in order to be on the safe side. Tidal waters already have such a large eventual rate of spreading that tidal waters are resilient repositories for degradable human and industrial waste (SMITH and SCOTT, 1997). The tidal conditions of the study area are summarized in Table 1 (KABDA, 2003a-b). Here, a complete tidal period is 24 hours.

Temperature measurements were performed with nine Pt 100 type 100 at 0°C heat probes (digital thermometers) with 0.1°C sensitivity their placement was shown on Figure 1. The design temperature difference between the discharged water and the sea water, 8°C, was created by using thermo-couple heaters with a total power of 210 kW placed in the heating tank (Figure 1). The heating units were controlled by a thermostat unit to heat the discharge water at the desired excess temperature. Also conventional temperatures were used to measure the ambient temperature (water and air).

The heat probes were connected to a central PLC unit which had recorded the temperature values from all probes in a synchronized manner.

**Test Procedure**

A control point defined by the Ministry of Environmental Affairs of Oman (600 m seaward from the discharge point) was investigated that according to the specifications at the end of seven tidal cycles the mean excess temperature at 1 m depth (with respect to Chart Datum CD) should be less than 1°C. For this purpose 3 of the nine heat probes were placed on this location at levels ±0 mCD, 1 mCD and 3 mCD (at the sea bottom), respectively (Figure 1a). All other probes were fixed at the ±0 mCD level.

Starting from LAT (Lowest Astronomical Tide), the model had been run continuously for 7 complete tidal cycles which lasts seven days in prototype scale and 21 hours in model scale. During the model run, the tidal levels and current (velocity and direction) were controlled by pumps and monitored by the ADV device with 1 Hz sampling frequency. The temperature data from all heat probes was recorded by using the PLC unit automatically at every 10 minutes of the tidal period.

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**RESULTS AND DISCUSSIONS**

Temperature measurements were recorded for 7 tidal cycles with 10 minutes intervals as time series. The overall mean values and the means of each cycle are given in Table 2. The probe numbers are referred to Figure 1. The control point is measured by probe No. 5. The initial mean sea water temperature was measured to be 16.75°C in the model.

The temperature variations at the control point were determined for the three probes 12, 5, 6 (Figure 2). A significant periodicity in the time series can easily be recognized. There is also a phase shifting in between the data as there are certain distances between the probes. This shows how the heat disperses.

Figure 3 presents the heat distribution during a sample tidal cycle which may be representative for the heat distribution characteristics within a cycle. As can be seen from the figure at the end of 1st quarter of a tidal period the heated water is starting to spread out the basin. When the isotherms regarding the half time of a tidal period are examined the intrusion of thermal discharge is more dominant. In the last two diagrams, 3T/4 and T, the rising water level and incoming current seem to balance the temperature distribution within the basin. In all the stages of
Figure 2. The spatial variation of temperature with respect to run time at probe 12, 5 and 6, which are located at ±0.00 mCD (surface), 1.00 mCD and 3.00 mCD (bottom) level, respectively (For placement of the probes see in Figure 1).
tidal cycle it is clear that the heat diffusion is towards the heading current direction. This is because the convective term is dominant in the heat dispersion equations. In all cases it is possible to see the isotherms, shaped as tongue, showing the heat dispersion through the tidal path.

The coordinate system for ADV used to monitor the tidal current during the model run is shown in Figure 1. At the end of seven tidal cycles, the mean velocity in $x$ and $y$ direction was found to be 1.40 m/s and 0.32 cm/s, respectively.

CONCLUSIONS

In this study diffusion of the heat from discharge point under the tidal effect was studied in physical model. Following conclusions can be drawn from this study:

- The allowed limit of the control point for the mean temperature rise was 1°C, as given from authority. Due to the results, temperature in that point always was taken the lower values that that limit.
- Mean temperature values of this point within a tidal cycle was determined stationary (Figure 1); meaning that, it does not seem to have an increasing trend with the repetition of tidal cycles.
- Feedback mechanism between the outfall and intake points was not observed (Figure 2). With this conclusion, the breakwater can be said to be efficient as far as the prevention of the feedback is concerned.
- Reducing effects like wave fluctuations and atmospheric cooling due to wind effect were not included in this model study. But in prototype conditions, these factors will be doubtlessly contributing the cooling of the water.

### Table 2. Recorded mean temperature values in °C.

<table>
<thead>
<tr>
<th>Mean Temperature in Celsius</th>
<th>Probe 1</th>
<th>Probe 2</th>
<th>Probe 3</th>
<th>Probe 4</th>
<th>Probe 5</th>
<th>Probe 6</th>
<th>Probe 7</th>
<th>Probe 8</th>
<th>Probe 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Mean</td>
<td>16.578</td>
<td>17.162</td>
<td>22.150</td>
<td>24.914</td>
<td>17.384</td>
<td>16.192</td>
<td>24.397</td>
<td>17.110</td>
<td>17.151</td>
</tr>
</tbody>
</table>

Figure 3. The temperature distribution over the model area for the fifth tidal cycle. Figures 2a, 2b, 2c and 2d show T/4, T/2, 3T/4 and T, respectively, where T is the tidal period. The legend for isotherms is given on the left in °C.
LITERATURE CITED


