Numerical Modeling of The Effects of Reclamation and Proposed Infrastructures on Thermal Dispersion of Power Plant Wastewater at PLTGU Muara Karang, Jakarta Bay

H Khoirunnisa1*, M Wibowo1, G Gumbira2, W Hendriyono1, and S Karima1
1 Centre of Technology for Maritime Industrial Engineering (PTRIM) - Agency for the Assessment and Application of Technology (BPPT), INDONESIA
2 Laboratory for Harbor Infrastructures and Coastal Dynamics (BTIPDP) - Agency for the Assessment and Application of Technology (BPPT), INDONESIA
Corresponding author’s: hanah.khoirunnisa@bppt.go.id

Abstract. Reclamation plan in Jakarta Bay close to the power plant cooling water discharge location. It will affect hot water distribution system and possibly increase water temperature around the power plant intake location. The increase in water temperature at the intake location will disrupt the operation of the power plant. The impact of hot water discharge to the intake location can be reduced by extending the intake channel and building barrier walls as planned by the Muara Karang Power Plant. Modeling is done with 3 scenarios, namely the existing condition, the existence of the reclamation island, and the proposed infrastructure around the power. This modeling aims to determine the effect of the reclamation island on heat distribution, especially around the intake location and the effectiveness of the infrastructures in minimizing the problem. Simulation for the east and west monsoons is done in 3 dimensions with MIKE3 Flow Model FM (DHI) by applying temperature function. Overall, the presence of reclamation island will increase the average temperature at the intake by 0.32 to 0.7°C compared to the existing conditions, and the proposed infrastructure is quite effective to reduce the temperature at the intake by 0.5 to 0.8°C.

1. Introduction
The Muara Karang gas and steam power plant (PLTGU) is located in North Jakarta, DKI Jakarta. The Muarakarang Generation Unit is under the management of PT PJB as a power generation unit for state-owned electrical energy producers. The Muarakarang Power Unit lies on the coast of Jakarta, in the Pluit Village, North Jakarta. It generates up to 1,614 MW of electrical power which supports the capital city of DKI Jakarta, especially in vital areas such as the State Palace, the Sudirman business district and so on. The Muarakarang Power Unit consists of two-unit blocks, namely Block 1 with a capacity of 500 MW and Block 2 with a capacity of 1100 MW [1]. Every year it generates approximately 7.900 GWh of electricity which is channelized through the 500 kV Extra High Voltage and the 150 kV High Voltage Air Channels to Java and Bali interconnection.

Heat dispersion depends on the current pattern around the PLTGU or PLTU, so that the tides have an effect on the temperature distribution [2]. The most basic physical process in heat transport is when the waste heat enters the water body, causing the water temperature to increase until it loses the heat balance on the surface [3]. One of the things that affects the temperature distribution around the Muara
Karang PLTGU is the current velocity condition, which also plays a very important role in human activities and the survival of marine life [4]. Based on the hydrodynamic simulations that have been carried out by the Korean team by considering the design of the reclaimed island, water quality problems cannot be ignored [5]. Hydrodynamic modeling in Jakarta Bay has also been carried out by van der Wulp, et al, 2016, and it shows that the total river discharge entering Jakarta Bay varies from 90 - 377 m$^3$s$^{-1}$ with an average of 204.8 m$^3$s$^{-1}$ [6]. The heat distribution around the Muara Karang PLTU is influenced by the discharge from the Muara Karang PLTU [7]. Modeling of heat dispersion is done using the MIKE 3 Flow Model FM, because it has fairly good verification results where the temperature difference between the model and field results is less than $<$0.5°C and valid up to $\pm$ 2 km [3][8].

The temperature distribution around the Muara Karang PLTGU has changed due to the existence of reclaimed islands G and H, depending on the current speed [9]. Regulation of the State Minister for the Environment Number 08 of 2009 concerning Wastewater Quality Standards for Thermal Power Plant Businesses and / or Activities states that the maximum level of discharge temperature from cooling sources is 40°C [10]. Meanwhile, Regulation of the State Minister for the Environment Number 51 of 2014 concerning Wastewater Quality Standards for Industrial activity, the range of maximum temperature for the environment is 38°C – 40°C [11]. Whereas in the Decree of the State Minister for the Environment Number 51 of 2004 concerning Sea Water Quality Standards, it is stated that the seawater quality standards for coral ecosystems are 28 - 30°C, mangroves 28 - 32°C, and seagrass 28 - 30°C [12].

This simulation aims to obtain the effectiveness value of the PLTGU design in reducing heat caused by the reclamation island. In addition, this simulation is carried out to calculate the vertical temperature distribution for the existing condition, with the presence of reclaimed island, and finally with the design of the PLTGU intake channel.

2. Data and Method

2.1 The Input Data
Thermal dispersion modeling in Jakarta Bay uses the results from hydrodynamic (HD) modeling as input. The HD model was done with an area of about 32408 m x 61714 m, using the tidal data extracted from the Tidal Model Driver (TMD) [13] for two years (January 2019 - December 2020) at a one hour time interval. The wave height and wind speed data for Jakarta bay area are gathered from the European Center for Medium-Range Weather Forecasts (ECMWF) [14] with a longterm data length of 6 years (2014 - 2019) at a time interval of 3 hours. The bathymetry data used as the model domain are obtained by combining the data from The General Bathymetric Chart of the Oceans (GEBCO) and National Bathymetry (BatNas) with a resolution of 180 m x 180 m as secondary data, while the bathymetry contour was drawn using the echo sounding raw data provided by Indonesia Ministry of Public Works and Housing (PUPR) [5] and Bappenas.

The output from HD modeling are surface elevation, velocity and current direction, which are then used in heat (thermal) dispersion modeling [15]. Water temperatures at the intake and outfall are obtained from the Muara Karang power plant. These values are made constant during the modeling time. The locations of the inlet and outfall, as well as the discharge (at constant value) of PLTU Muara Karang are listed as shown in the Table 3 [16]. Additional input data used in this model is the river discharge flow from SLHD Jakarta (Table 1) [17].
Table 1. River discharges around Jakarta Bay [17]

| No | Name                  | Easting     | Northing    | Discharge (m$^3$s$^{-1}$) |
|----|-----------------------|-------------|-------------|---------------------------|
| 1  | Dadap                 | 690773.15   | 9327067.38  | 10                        |
| 2  | Kamal                 | 691087.29   | 9326348.33  | 35                        |
| 3  | Cengkareng Drain      | 693804.42   | 9325423.97  | 55.56                     |
| 4  | Banjir Kanal Barat    | 694727.03   | 9325248.02  | 77.95                     |
| 5  | Ancol                 | 702367.55   | 9323471.58  | 2.17                      |
| 6  | Sunter                | 711033.19   | 9325525.28  | 13.02                     |
| 7  | Cakung Drain          | 714700.92   | 9325626.73  | 30.16                     |
| 8  | Banjir Kanal Timur    | 717915.34   | 9326224.88  | 50                        |
| 9  | Blencong              | 716671.71   | 9325961.39  | 5                         |
| 10 | Citarum               | 720294.21   | 9342942.05  | 78                        |
| 11 | Citarum               | 680870.68   | 9336378.68  | 70                        |

2.2 Numerical Equations

The advection–dispersion equation is used in this modeling [18], as described below.

$$\frac{\partial (\Delta T)}{\partial t} = - \frac{\partial u (\Delta T)}{\partial x} - \frac{\partial v (\Delta T)}{\partial y} + \frac{\partial}{\partial x} \left( A_p \frac{\partial (\Delta T)}{\partial x} \right) + \frac{\partial}{\partial y} \left( A_p \frac{\partial (\Delta T)}{\partial y} \right) + \frac{J}{\rho C_p H}$$ (1)

In addition, the transport–diffusion equations are also used [21].

$$\frac{\partial T}{\partial t} + \frac{\partial (\Delta T)}{\partial x} + \frac{\partial (\Delta T)}{\partial y} + \frac{\partial (\Delta T)}{\partial z} = F_T + \frac{\partial}{\partial z} \left( D_p \frac{\partial (T)}{\partial z} \right) + \tilde{H} + T_S S$$ (2)

$$\frac{\partial s}{\partial t} + \frac{\partial (\Delta s)}{\partial x} + \frac{\partial (\Delta s)}{\partial y} + \frac{\partial (\Delta s)}{\partial z} = F_s + \frac{\partial}{\partial z} \left( D_p \frac{\partial (s)}{\partial z} \right) + \tilde{H} + S_S S$$ (3)

whereas t is time, (x, y, z) are a cartesian coordinates, (u, v, w) are flow velocity components, (T, s) as temperature and salinity, $D_p$ is a vertical turbulent (eddy) diffusion, $\tilde{H}$ is source term due to heat exchange with atmosphere, $S$ is magnitude of discharge due to point sources, $(T_S, S_S)$ as temperature and salinity of source.

2.3 Simulation Design

Thermal dispersion modeling was done in two periods, west monsoon (January) and east monsoon (July). The 3D MIKE 3 Flow Model FM was used with the following setup parameters:

Table 2. Thermal dispersion modelling setup parameters

| Parameter                          | Value                           |
|------------------------------------|---------------------------------|
| Horizontal dispersion              | 0.01 m$^3$s$^{-1}$              |
| vertical dispersion                | 0.0001 m$^3$s$^{-1}$            |
| The ambient temperature as initial | 30.5°C                          |
| Density                            | Function of temperature         |
| Eddy viscosity                     | No Eddy                         |
| North Boundary                     | Surface elevation from hydrodynamic simulation |
| East Boundary                      | (Time interval: 1 hour)         |
| West Boundary                      |                                 |
| South Boundary                     | Land Boundary                   |
Figure 1. Location of hydrodynamic (HD) modelling in Jakarta Bay

Table 3. PLTGU Muara Karang’s outfall location and their discharge [16]

| Location     | Easting | Northing | Discharge (m$^3$s$^{-1}$) |
|--------------|---------|----------|---------------------------|
| outfall 1    | 697000  | 9324800  | 14.4                      |
| outfall 2    | 698500  | 9325400  | 30.4                      |
| intake 1     | 697558  | 9324407  | 15.08                     |
| intake 2     | 697558  | 9325200  | -35.07                    |

2.4 Model Scenario

Thermal dispersion simulation in Muara Karang PLTGU used three scenarios, namely “existing”, “existing + reclamation island”, and “PLTGU design” (Figure 2, 3, and 4). The particular PLTGU design comprises a number of structures (horizontal wall, vertical wall, intake extension, and the reclaimed island) around the intake and outfall (Figure 5).

Figure 2. Thermal dispersion model domain for existing scenario

Figure 3. Thermal dispersion model domain for PLTGU design scenario

Figure 4. Thermal dispersion model domain for existing + reclamation island scenario

Figure 5. Particular PLTGU design: vertical wall, horizontal wall, intake extension and reclamation island
3. Results and Discussion
Figures 6 to 11 show the conditions of temperature and current direction for the three scenarios (existing, PLTGU design, and existing+spatial reclamation islands). During the west season (January), the direction of the current goes to the east, while during the east season (July), the current is directed toward the northwest. The spatial average value of temperature in the east monsoon (July) is higher than the temperature during the west monsoon (January). For the existing condition, the average temperature during the west monsoon is 31.05°C with an average current speed of 0.062 m/s, while during the east monsoon the average temperature is 32.125°C with an average current speed of 0.046 m/s.

In the PLTGU design scenario, the average temperature during the west monsoon is 31.309°C with an average current speed of 0.054 m/s, while during the east monsoon, the average temperature is 31.98°C with a current speed of 0.042 m/s. Based on Table 4, it can be seen that the largest average temperature value during the west season occurs for the “PLTGU design” scenario, while during the east monsoon, it occurs for the “existing + reclamation islands” scenario.

### Table 4. The average temperature and current speed during west and east monsoons

| Scenario                        | Temperature (°C) | Current Speed (m/s) |
|---------------------------------|------------------|---------------------|
| **January**                     |                  |                     |
| Existing                        | 31.1             | 0.062               |
| PLTGU Design                    | 31.3             | 0.054               |
| Existing + Reclamation Island   | 30.7             | 0.055               |
| **July**                        |                  |                     |
| Existing                        | 32.1             | 0.046               |
| PLTGU Design                    | 32.0             | 0.042               |
| Existing + Reclamation Island   | 32.2             | 0.041               |

### Table 5. The maximum temperature and current speed during west and east monsoons

| Scenario                        | Temperature (°C) | Current Speed (m/s) |
|---------------------------------|------------------|---------------------|
| **January**                     |                  |                     |
| Existing                        | 35.5             | 2.538               |
| PLTGU Design                    | 35.5             | 2.539               |
| Existing + Reclamation Island   | 35.5             | 2.539               |
| **July**                        |                  |                     |
| Existing                        | 35.5             | 1.468               |
| PLTGU Design                    | 35.5             | 1.466               |
| Existing + Reclamation Island   | 35.5             | 1.467               |

![Figure 6. Thermal dispersion result of existing scenario at west monsoon (January)](image1)

![Figure 7. Thermal dispersion result of existing + reclamation island scenario at west monsoon (January)](image2)
Figures 14 - 17 show the variation of temperature with water depth (vertical variation) for the “existing + reclamation” and “PLTGU design” scenarios during the west and east monsoons along the intake channel (Figure 14). It can be seen in Figures 14 and 15 that the values of water temperature at location 4 in the “PLTGU design” scenario are higher than the “existing + reclamation” scenario. Conversely, as seen in Figure 16 and 17, during the eastern monsoon, the water temperature for the PLTGU design scenario is lower than the temperature for the “existing + reclamation” scenario.
Figure 18 shows the temperature conditions at 0.5 m, 1.5 m, 2.5 m and 3.5 m water depth for existing condition during west monsoon (represented by January), implying a fairly stable condition where the temperature ranges from 30.5 to 32.2°C. However, during the eastern monsoon (represented by July), the water temperature at each depth has an increasing trend at the beginning of the simulation and has a smaller range than the west monsoon, namely 31.2 - 32.2°C.
monsoon represented by July, the temperature condition at each depth tends to be more stable and has a smaller range than the western monsoon, namely 31.82 - 32.39°C.

Figure 20 shows the temperature conditions at 0.5 m, 1.5 m, 2.5 m and 3.5 m water depth for “PLTGU design” condition during west monsoon (represented by January), where for each depth the temperature ranges from 30.5 to 31.85°C. Meanwhile, during the eastern monsoon represented by the month of July, the temperature conditions at each depth ranges from 30.5 to 31.5°C.

Table 6 shows that the highest average temperature in January (west season) occurs in the “existing + reclamation” scenario at a depth of -0.5 m with a value of 31.69°C and the lowest average temperature occurs in the “PLTGU design” scenario with a value of 31.14°C. In addition to obtaining the temperature distributions for the three scenarios, the thermal dispersion simulation also aims to obtain the effects of the “PLTGU design” and the “Existing + Reclamation” scenarios compared to the “existing” scenario. Based on Table 7, it is found that the PLTGU design scenario is able to reduce heat at each intake depth by up to 1.24% during the west season and 1.12% during the east season. On the other hand, the “existing+reclamation” configuration would increase the water temperature at each depth at the intake by 1.29% during the east season and 0.5% during the west season.

Therefore, the effectiveness of the “PLTGU design” against the “existing+reclamation” can be calculated using the values listed the Table 8. As seen from the Table below, it is found that the PLTGU design is able to reduce heat from the “existing+reclamation” scenario by up to 1.86% during the west season and 2.65% during the east season.
Table 6. Temperature at various water depths (0.5m; 1.5m; 2.5m; and 3.5m) during west and east monsoons (°C)

| Scenario    | January Depth (m) | July Depth (m) |
|-------------|-------------------|----------------|
|             | -0.5 | -1.5 | -2.5 | -3.5 | -0.5 | -1.5 | -2.5 | -3.5 |
| PLTGU Design| 31.14 | 31.08 | 31.02 | 30.98 | 31.21 | 31.17 | 31.13 | 31.09 |
| Eks + G Island| 31.69 | 31.64 | 31.59 | 31.56 | 32.03 | 31.99 | 31.96 | 31.94 |
| Existing    | 31.53 | 31.25 | 30.98 | 30.83 | 31.56 | 31.51 | 31.46 | 31.41 |

Table 7. The effects of “PLTGU design” and “existing+reclamation” on temperature changes with respect to existing condition (%)

| Scenario     | JANUARY Depth (m) | JULY Depth (m) |
|--------------|-------------------|----------------|
|              | -0.5 | -1.5 | -2.5 | -3.5 | -0.5 | -1.5 | -2.5 | -3.5 |
| PLTGU Design | 1.24 | 0.53 | -0.13 | -0.47 | 1.12 | 1.10 | 1.05 | 1.01 |
| Eks + G Island | -0.50 | -0.36 | -0.21 | -0.10 | -1.58 | -1.48 | -1.37 | -1.29 |

Table 8. The effectiveness of “PLTGU design” against “existing+reclamation” scenario (%)

| Depth (m) | JANUARY Effectivity (%) | JULY Effectivity (%) |
|-----------|-------------------------|-----------------------|
| -0.5      | 1.73                    | 1.77                  |
| -1.5      | 1.77                    | 1.81                  |
| -2.5      | 1.86                    | 2.56                  |
| -3.5      | 2.65                    | 2.65                  |

The next analysis concerns with the temperature changes along the A-B and C-D lines, which are the outfall from PLTGU Muara Karang, as shown in Figure 22. The temperature changes along A-B and C-D for the existing, existing + reclamation, and PLTGU design are shown in Figures 23 to 26. Comparing the temperature conditions between January and July, it can be seen that there is almost no difference along the line A-B, while a substantial difference is observed along C-D.

The temperatures in July are lower than in January. It can be seen in Table 9 that the highest average temperature value occurs for the “existing-reclaimed island” during the west season (January) with a value of 35.17°C, while the lowest average temperature (34.84°C) occurs for the “existing” scenario during the same season. Along A-B, the mean temperature during east season is smaller than the mean temperature during the west season for all scenarios (Table 9).

However, Table 10 shows that along C-D, the average temperature for the “PLTGU design” scenario during the east season (July) is lower compared to both the “existing” and “existing+reclamation” scenarios.

Table 9. Average temperature along A–B

|              | PLTGU Design (°C) | Existing + G Island (°C) | Existing (°C) |
|--------------|-------------------|--------------------------|---------------|
| January      | 35.16             | 35.17                    | 34.84         |
| July         | 35.08             | 34.99                    | 34.86         |

Table 10. Average temperature along C-D

|              | PLTGU Design (°C) | Existing + G Island (°C) | Existing (°C) |
|--------------|-------------------|--------------------------|---------------|
| January      | 32.32             | 31.89                    | 32.25         |
| July         | 31.73             | 32.52                    | 32.32         |
4. Conclusions
Thermal dispersion modeling was carried out for two periods, namely the west season and the east season. From the analyses of the modelling results, it is found that the spatial average temperature during the west monsoon (January) is lower compared to that during the east monsoon (July) for existing condition, “existing+reclamation” and “PLTGU design”. From the analysis of variation of temperature with water depth, it was found that if compared to the existing condition, the “PLTGU design” scenario is able to reduce the heat by up to 1.24% and 1.12% during the west and east monsoons respectively. Meanwhile, if compared to the “existing+reclamation” scenario, the effectiveness of the proposed “PLTGU design” is found to reduce the temperature by 1.86% for the west season, and 2.65% for the east season. Extracting the results along the lines from both outfalls has shown that during the west season, the highest average temperature along A-B (west outfall) occurs for the “existing+reclamation” scenario with a value of 35.17°C, while during the east season the highest average value of 35.08°C occurs for the “PLTGU design” scenario. Along C-D (east outfall), the highest average temperature during the west monsoon occurs for the “PLTGU design” scenario with a value of 32.32°C, while the highest average temperature of 32.52°C during the east monsoon occurs for the “existing+reclamation” scenario.

5. References
[1] Rosyidin W F, Sunarto S, Sribrotopuspito K, Wisesa A, Dahlia S 2017 Awareness Capacity of Muara Karang Generator Unit to Face the Failure of Environmental Impact Technology. Geo Edukasi 5(2)
[2] Anam, C 2015 Studi Pola Sebaran Panas Air Pendingin di PT. Pembangkitan Jawa-Bali Unit Pembangkit Gresik (PT. PJB UP Gresik). Doctoral dissertation, Institut Teknologi Sepuluh Nopember
[3] Nurjaya I W and Surbakti H 2010 Thermal Dispersion Model of Water Cooling PLTGU Cilegon Ccpp Discharge Into Margasari Coastal Waters at the Western Coast of Banten Bay. J. Ilmu dan Teknologi Kelautan Tropis 2(1)
[4] Setiawan A and Putri M R 1998 Study of current circulation in Jakarta Bay. Proceed. of the 3rd Int. Sym. on Adv. and Aerospace Sci. and Tech. in Indonesia. Agency for Assessment and Application of Technology 803-810

[5] Jun P B and Chol L J 2019 Review of Alternatives for Jakarta NCICD Project using Numerical Modeling. 3rd World Irrigation Forum (WIF3)

[6] Van der Wulp S A, Damar A, Ladwig N and Hesse K J 2016 Numerical simulations of River discharges, nutrient flux and nutrient dispersal in Jakarta Bay, Indonesia, Marine pollution bulletin 110(2) 675-685

[7] Mihardja D K, Fitriyanto M S and Putri M 1999 Modelling of the heated water spreading in Muara Karang coastal waters, Jakarta Bay J. of Math. and Fund. Sci. 31(1) 5-18

[8] Wibowo M and Asvaliantina V 2018 Kajian Dispersi Panas Akibat Air Limbah Rencana Pembangunan PLTU Kuala Tungkal-Provinsi Jambi J. Teknologi Lingkungan 19(1) 1-12

[9] Islami A 2018 Pemodelan sebaran panas limbah air kanal pendingin PT. PJB UP Muara Karang pasca dan masterplan reklamasi serta analisis hubungannya terhadap kelimpahan Fitoplankton, Doctoral dissertation, UIN Sunan Ampel Surabaya

[10] Indonesian Government 2009 Regulation of the State Minister for the Environment Number 08 of 2009 concerning Wastewater Quality Standards for Thermal Power Plant Businesses and/or Activities

[11] Indonesian Government 2014 Regulation of the State Minister for the Environment Number 51 of 2014 concerning Wastewater Quality Standards for Industrial activity

[12] Indonesian Government 2004 Decree of the State Minister for the Environment Number 51 of 2004 concerning Sea Water Quality Standards

[13] Padman L and Erofeeva S 2005 Tide Model Driver (TMD) Manual Earth and Space Research

[14] Molteni F, Buizza R, Palmer T N and Petroliagis T 1996 The ECMWF ensemble prediction system: Methodology and validation. Quarterly journal of the royal meteo. soc. 122(529) 73-119

[15] MIKE 21 Hydrodynamic Module 2012 Scientific Documentation DHI. Denmark

[16] PT. Pembangkitan Jawa Bali Unit Pembangkitan Muara Karang

[17] Status Lingkungan Hidup Daerah DKI Jakarta 2015 Dinas Lingkungan Hidup Provinsi DKI Jakarta

[18] Ramming H G and Kowalik Z 1980 Numerical Modelling of Marine Hydrodynamics: Applications to Dynamic Physical Processes Elsevier Scientific Publishing Company. Amsterdam