Simulation of Thermal Dispersion in Location of Development of Diesel Power Plant Using Computational Fluid Dynamics Methods

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Abstract. Electrical energy is one of the important energy needs in human life. To meet the electricity needs in the North Maluku area, it was planned to build a diesel power plant (PLTD) in the coastal area of Halmahera. In the activity of the power plant, it produces heat wastewater from the rest of the radiator cooling process. This study, conducted a numerical simulation to determine the thermal dispersion pattern of waste heat from PLTD cooling water in Halmahera waters. Modeling the dispersion of heat waste temperature of PLTD cooling water is carried out using the Ansys CFD (Computational Fluid Dynamics) method in 3D. The input data are in the form of heat water discharge of 4,000 tons/hour, with heat wastewater temperature 37.5 °C. Ambient seawater temperature is 30.5 °C and seawater density is 1022 kg/m³. Hydrodynamic modeling of oceanic currents is modeled with two variations, namely constant current of 0.4 m/s and UDF current. UDF currents have different current values for each depth with a current velocity of 0.005 m/s up to 0.4 m/s. The simulated results of a constant current show the spread of heat to the environment occurs as far as 210 m to the north of the discharge outlet. The highest temperature value is 37.14 °C, the lowest is 30.8 °C. For these UDF current models, the heat spread is 210 m to the north of the discharge outlet with the highest temperature value is 37.13 °C the lowest is 30.61 °C.

1. Introduction
Indonesia’s electricity consumption continues to show improvement as technology develops and changes in people's lifestyles. Based on data from the Ministry of Energy and Mineral Resources (Kemen-ESDM), electricity consumption increases every year, in 2017 it reached 1021 KWH/Capita increased 5.9% from the previous year (1). Halmahera, North Maluku is an area with an electricity supply that is still inadequate, so there are still areas that have not yet been electrified. To meet the electricity needs, a power plant is needed. One of the plans to build a diesel power plant (PLTD) on the coast of Halmahera, North Maluku. The construction of a power plant in the coastal area aims to facilitate the fulfillment of cooling water needs. Cooling water that has been used thrown back into the sea has a higher temperature value than the ambient temperature. The increase in temperature due to waste heat from cooling water can reach 2-15 °C (2). This raises the main problem, namely, with the
rise in seawater temperature due to the waste heat of cooling water above 2 °C will affect the life of the biota, flora, and fauna in the sea (3). The temperature that can be tolerated by fish and marine biota is 38.1 °C, crustaceans 37.9 °C and mollusks 36.7 °C (4). The rule of the environment minister that the difference in discharge temperature with natural temperature is 2 °C, it is necessary to study the thermal dispersion of wastewater (5).

The study of oceanographic characteristics and seawater quality at the location of the power plant is an important activity as a reference in planning the construction of a power plant (6). One of them is a simulation of thermal dispersion models. This thermal dispersion model based on thermal advection-dispersion equations shows the value of temperature rise that occurs due to the waste heat of cooling water (7). Mardi and Velly (8) modeling thermal dispersion in the case of the Kuala Tungkal PLTU in Tanjung Regency, Jambi Province, Indonesia is using the MIKE 3 software. The discharge value of heat wastewater was 5000 m³/hour, heat wastewater temperature was 33 °C and 29 °C ambient temperature. The results obtained are the distribution of heat wastewater with a temperature increase of 0.5-1 °C occurring as far as 300 meters from the location of the discharge. Whereas the area with a temperature increase of 2 °C is 45 meters to the north from the location of the discharge.

Simulation and analysis of distribution patterns of wastewater temperature of PLTD cooling water in Halmahera waters were carried out using the 3D Computational Fluid Dynamics (CFD) method. Modeling input data in the form of temperature data, bathymetry, and ocean currents (9). This modeling is done to predict the extent of the effects of thermal pollution by PLTD cooling water discharges so that it can determine the optimal placement of the intake and discharge outlets and to avoid rising natural temperatures above the permitted standard (10).

2. Research Methods

2.1 Validation
Validation is done to determine the boundary conditions that will be used in modeling. Validation simulations were carried out based on previous research on thermal dispersion carried out by Shaikh in 2015 (11). The geometry of the journal is a 3D model with dimensions of 70x50x8 meters. In the process of generating mesh skewness values based on Ansys, standards are said to be good if the value is below 0.9. In this validation, mesh elements with the number of grid 291.553 have a skewness of 0.4 value indicating good mesh quality. Simulation is done with the k-epsilon turbulence model and the boundary conditions in the validation model are ambient inlet, hot inlet, and outlet. After the simulation, the contour results of the temperature distribution between the journal and the simulation have a match where the error value is below 10%. The error value is shown in Table 1.

| Parameter                  | Modeling       | % Error |
|----------------------------|----------------|---------|
| Local Temperature          | 20.67 °C       | 0.53%   |
| Maximum Temperature        | 22.02 °C       | 6.13%   |

2.2 Modeling Area
The area of thermal dispersion modeling is in the waters of Halmahera, North Maluku geographically located at coordinates 00°41‘46.6”N - 127°32’57.7” E.
2.3  Governing Equations
The governing equation used is the continuity equation, momentum equation, and advection-dispersion. The equation of the fluid motion model used is the continuity equation, where the momentum equation for the three-dimensional model is written as follows:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]  \(2.1\)

\[
\rho \frac{Du}{Dt} = \frac{\partial (-p + \tau_{xx})}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + S_{mx}
\]  \(2.2\)

\[
\rho \frac{Dv}{Dt} = \frac{\partial (-p + \tau_{yy})}{\partial y} + \frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \tau_{zy}}{\partial z} + S_{my}
\]  \(2.3\)

\[
\rho \frac{Dw}{Dt} = \frac{\partial (-p + \tau_{zz})}{\partial z} + \frac{\partial \tau_{zx}}{\partial x} + \frac{\partial \tau_{zy}}{\partial y} + S_{mz}
\]  \(2.4\)

Then the thermal dispersion model is made using the Advection / Dispersion equation. The advection-dispersion model is solved by three-dimensional equations. The equation can be written as follows (12):

\[
\frac{\Delta T}{\partial t} = \frac{\partial (\Delta T)}{\partial x} - \frac{\partial v(\Delta T)}{\partial y} - \frac{\partial w(\Delta T)}{\partial z} - \frac{\partial}{\partial x} \left( A_d \frac{\partial (\Delta T)}{\partial x} \right) + \frac{\partial}{\partial y} \left( A_d \frac{\partial (\Delta T)}{\partial y} \right) + \frac{\partial}{\partial z} \left( A_d \frac{\partial (\Delta T)}{\partial z} \right) + \frac{J}{\sigma C_p H}
\]  \(2.4\)

2.4  Model Input Data
2.4.1  Bathymetry
The bathymetry map shows depth lines and land boundaries. The depth value in the modeling waters is worth 0-28 meters. Then this bathymetric map is used as a reference for making computational domain geometry. The boundary conditions of computational domain modeling on bathymetry maps are 267x293 meters with black lines shown in Figure 1. These boundary conditions are land prepared by PLN and have obtained permission from the government to build a diesel power plant.
Ocean currents in Halmahera waters were obtained from field measurement data conducted in November 2017 with locations at coordinates 00°41'46.6" N - 127°32'57.7" E. From the results of measurements as long as 3x24 hours it was found that the current was dominated by non-tidal currents where the current direction was dominated from south-southeast towards the north. Current values range from 0-0.55 m/s. The maximum current value of 0.55 m/s is at a depth of 2 meters. The current data used in modeling are the north direction by taking the current maximum value of north by 0.4 m/s.

2.5 Model Scenario

2.5.1 Ocean Current Model
Hydrodynamic modeling will be simulated in 2 models of ocean currents. The first ocean current model is constant ocean currents with a value of 0.4 m/s and the direction of the current heading north. The second model of ocean currents, using UDF currents. The UDF feature in fluent makes users more freedom to develop the boundary conditions, material properties, and change modeling parameters to improve post-processing. Where in the modeling of this thermal dispersion, the function of UDF is used to arrange the boundary condition at each depth where the current speed has different values. For a depth of 1 meter to 7 meters at 0.4 m/s, a depth of 8 meters is 0.38 m/s, a depth of 12 meters is 0.34 m/s, a depth of 16 meters is 0.28 m/s, into 20 meters is 0.2 m/s, 24 meters depth of 0.11 meters and 28 meters depth of 0.005 m/s.

2.5.2 Heat Distribution Model
The heat distribution modeling geometry is made using Solidwork software, with dimensions based on boundary conditions on the bathymetry map, which is 267x293x28 meters. The waste heat output area of the discharge has a diameter of 0.9 meters and is at a depth of 5 meters. In this activity, the assumption used is the Halmahera PLTD which will discharge 4,000 tons/hour of water and have a temperature value of 37.5 °C. The temperature of seawater is constant throughout the modeling of 30.5 °C. The modeling geometry is shown in Figure 2.
Figure 2. Geometry of Modeling Thermal Dispersions and Areas of Boundary Conditions.

2.5.3 Simulation Operation Boundary Conditions
The boundary conditions used in thermal dispersion modeling simulations are obtained, based on the results of the journal validation that has been carried out. Parameters for modeling boundary conditions are presented in Table 2.

Table 2. Parameter of Boundary Condition Modeling of Thermal Dispersion

| Parameter                            | Value                                      |
|--------------------------------------|--------------------------------------------|
| Computational Domain                 | 297 x 293 x 8 m                            |
| General Setting                      | a. Pressure-Based                          |
|                                      | b. Steady                                  |
| Flow Models                          | a. Turbulent K - epsilon Realizable        |
|                                      | b. Energy Equation                         |
| Material                             | Water liquid                               |
| Boundary Conditions                  | a. Inlet: Velocity Inlet                    |
|                                      | b. Outlet: Outflow                         |
|                                      | c. Computational Domain Wall: Wall         |

3. Results and Discussion

3.1 Contour of Temperature Distribution in Every Depth
In this study modeled 2 variations of ocean currents there are constant current of 0.4 m/s and the UDF current, with the value of waste heat dissipation of 4,000 tons/hour and temperature of 37.5 °C. Furthermore, the temperature distribution at each depth and each distance from the discharge outlet position is observed.
From Figure 3 shows the temperature contour at a depth of 5 meters, where the discharge outlet position is. The maximum temperature rise value for the constant current model reaches 37.14 °C and for the UDF current model, it reaches 37.13 °C. From the simulation results at a depth of 1 meter has a temperature value of 31.35 °C. In areas with depths below 5 meters, the value of temperature rise is lower. Were at 13 depths the temperature value is 30.9 °C. The value of temperature at a depth of 13 meters is lower than the temperature at a depth of 1 meter or surface area. This happens because the lower part of the water with a high temperature has a lighter density value so that the water moves upward causing the upper water to rise in temperature.

3.2 Contour of Temperature Distribution Against the Position of the Discharge Outlet

Figure 4. Contour Temperature Distribution at Distance (a) 30 meters (b) 210 meters from the discharge outlet.

Constant Current Model with Figure 4. (a) Showing the temperature contour of the constant current model in an area with a distance of 210 meters from the discharge outlet position. In that area, the temperature of seawater temperature increases by 0.63 °C from 30.5 °C to 31.08 °C. Then Figure 4. (b) displays the temperature contour of the UDF current model at a distance of 210 meters from the discharge outlet where the seawater temperature has increased by 0.52 °C from 30.5 °C to 31.02 °C. While the area close to the discharge outlet there is a higher temperature increase, which reaches 2 °C. From the temperature value that has been known, shows the farther distance from the discharge outlet the value of rising temperature is getting higher. This is because heat transfer occurs between the waste heat of the cooling water and its surroundings along with the speed causing the temperature value to decrease.
3.3 Temperature Distribution

3.3.1 Plots of Temperature Chart for each Depth of Sea Water
The value of temperature rise due to waste heat of cooling water at each depth is plotted on a graph presented in Figure 5.

![Figure 5. Temperature Chart Against the Distance of North from the Discharge Outlet for Each Depth. (a) Constant Flow Model. (b) UDF Flow Model.](image1)

From Figure 5 it can be seen for the graph of the constant current, the lowest temperature is 30.8 °C at a depth of 7 meters with a distance of 210 meters to the north from the position of the discharge outlet. Whereas for UDF current the lowest temperature is 30.6 °C at a depth of 4 meters with a distance of 210.22 meters to the north from the discharge outlet position. The temperature distribution value of the UDF current model has a better result compared to the constant current model. This is because in UDF modeling the ocean currents being modeled are closer to the actual conditions where the seawater velocity will be smaller with increasing depth.

3.3.2 Plots of Contour Temperature Charts for Distance from Seashore

![Figure 6. Graph of Temperature Distribution of Distance from the Seashore. (a) Constant Flow Model. (b) UDF Flow Model.](image2)

Figure 6 showing a graph of the temperature values in the area of each 30 meters north of the outlet discharge viewed from the coastline. The graph of the temperature of seawater temperature begins to rise with a temperature value of 31 °C in an area 80 meters from the coastline and then rises to the height temperature of 32°C at a position 135 meters from the coastline. This shows that the highest temperature value is in the area near the discharge outlet. The biggest error values for peak values in Graphs 6 (a) and (b) of the temperature values in the constant current modeling and the UDF current are 0.22% where the constant current temperature is 31.45 °C and the UDF current
temperature is 31.52 °C. The temperature value of the UDF model is higher than the constant current model because in the modeling of UDF current the current value smaller with increasing depth. So that the flow speed is slower and causes a longer heat transfer.

4. Conclusion
The thermal distribution pattern of the cooling water PLTD is affected by the flow pattern or sea currents where the sea currents here are modeled with the north direction causing the heat distribution to points north from the discharge outlet position. The highest temperature due to thermal dispersion for constant current modeling is 0.4 m/s at a depth of 5 meters, which is 37.15 °C and the lowest temperature value is 30.8 °C at a depth of 7 meters. For the modeling of ocean currents using UDF the highest temperature rise value is at a depth of 5 meters, which is equal to 37.13 °C and the lowest temperature value is 30.61 °C at a depth of 4 meters. The value of the lowest temperature rise due to thermal dispersion is in the area with a distance of 210 meters north from the discharge outlet. For the constant current model is 0.63 °C and the UDF current model is 0.52 °C. The optimal placement for cooling water intakes of the PLTD is at a depth of 7 meters for the constant current model and a depth of 4 meters for UDF current model. With a position as far as 80 meters from the beach with a distance of 210 meters from the discharge outlet position.

Nomenclature

| Symbol | Description |
|--------|-------------|
| T      | Temperature (K) |
| J      | Heat Flux (W/m²) |
| H      | Depth of waste heat dispersion (m) |
| \( \sigma \) | Optimal depth of water (m) |
| A_D    | Koefisien diffusion in x and y direction (m²/s) |
| C_p    | Specific Heat (W/kg°C) |
| Q      | Debit (m³/s) |
| \( \rho \) | Density of fluid (kg/m³) |
| \( \tau_{xx} \) | Shear stress in x directions |
| \( \tau_{yy} \) | Shear stress in y directions |
| \( \tau_{zz} \) | Shear stress in z directions |
| \( \delta_{x} \) | x direction (m) |
| \( \delta_{y} \) | y direction (m) |
| \( \delta_{z} \) | z direction (m) |
| t      | Time (s) |
| u      | Velocity in x direction (m/s) |
| v      | Velocity in y direction (m/s) |
| w      | Velocity in z direction (m/s) |
| S_{nx} | Body force in x directions |
| S_{ny} | Body force in y directions |
| S_{nz} | Body force in y directions |
| p      | Surface Pressure |

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