Determination of Construction Design to Reduce the Amount of Marine Litter at Seawater Intake Using Particle Tracking Module of Numerical Method by Mike 21 (Case Study: Tanjung Awar - Awar, Tuban, East Java)

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Abstract. This research aims to analyze and estimate the amount of marine litter which get into seawater intake of PT Trans-Pacific Petrochemical Indonesia (TPPI) Tuban in existing conditions during west monsoon and east monsoon. Ten designs will be simulated to reduce and trap the marine debris entering the seawater intake (SWI). These designs will be tested for their effectiveness in reducing the number of debris entering the SWI using the particle tracking module of MIKE 21 numerical modelling package. The required data in this simulation are wind (speed and direction), wave (significant height, direction and period), the bathymetry of and coastline. Besides, this simulation is conducted based on primary data provided by TPPI Tuban management as the validation data. Based on the simulation results, the amount of marine litter entering SWI in the west monsoon is greater than the east monsoon, which is 349.14 kg/year for west monsoon and 100.84 kg/year for east monsoon. Based on the simulation results using the particle tracking module, it was found that design 5 is the most effective design, with the effectiveness of 73.97%. The biggest accumulation of marine litter using construction design 5 occurred in November, which was 355.36 kg.

Keywords: construction design, marine litter, numerical method, particle tracking, seawater intake introduction

1. Introduction

Based on research [1] regarding the analysis of metal pollution levels along the north coast of Tuban district, it was found that the category of the index of metal pollution along the Tuban coast is small to medium [2]. Based on [3], the litter is all things generated by human and animal activities in the form of solid, mud, liquid, or gas because they are no longer needed. Whereas based on [4], the litter is the remnants of human daily activities or natural processes in the form of solid. Grouping the composition of domestic litter based on [3] consists of:
Table 1. Grouping the composition of domestic litter [3].

| Litter categorized                | % Mass  | % Volume |
|-----------------------------------|---------|----------|
| Paper                             | 32.98   | 62.61    |
| Woods                             | 0.38    | 0.15     |
| Plastics and rubbers              | 6.84    | 9.06     |
| Fabric                            | 6.36    | 5.1      |
| Glass                             | 16.06   | 5.31     |
| Metal                             | 10.74   | 9.12     |
| Rock and Sand                     | 0.26    | 0.07     |
| Organic litters                   | 26.38   | 8.58     |

The litter accumulation in the ocean has very rapid growth to affect the health of the world's seas [5, 6]. Marine debris is defined as all solid objects that have been damaged and are not useful in the marine environment [5]. The types of litter which found in the sea are very diverse, but plastic has the greatest amount compared to other litter [6-9]. There are other studies that say that marine litter flows passively in the ocean and is in the sea surface layer. Marine debris can float at sea level and can also move at the subsurface layer [10]. Circulation in the upper layers of the ocean is strongly influenced by the speed of direct wind and Ekman currents [11]. Numerical modeling for marine debris tracking has been carried out by using HYCOM modeling with the help of data from the simple Ocean Data Assimilation (SODA) [10,11] including assimilation of all available data, the Global Ocean Data Assimilation Experiment (GODAE), ocean analysis/reanalysis system (ORA-S3) implemented by ECMWF [10,12,13]. Food waste and organic waste from traditional markets still have a very large percentage in the composition of waste in Indonesia. The same pattern also occurs in other developing countries such as India, Malaysia and Vietnam [14].

With the status as the world's top contributor of marine plastic debris, Indonesia has committed to reduce marine plastic debris up to 70% in 2025 by establishing the National Action Plan (NAP) on Marine Debris. The high amount of marine plastic debris as a result of transport and accumulation become a complex issue in Indonesia due to its ocean-atmospheric circulation, high population of coastal communities, and marine activities [15-17]. Based on [18-20], the type of marine debris can be broken-down into its material and is dominated with plastic. A study found that Indonesia's municipal marine debris is dominated by disposable diapers (21%), followed by plastic bags (16%), plastic packaging (5%) and other plastics (9%), glass and metal (4%) and plastic bottles (1%) [21].

At present, there are three technical issues in the company's port area P.T. Trans-Pacific Petrochemical Indotama (hereinafter abbreviated as TPPI), i.e. sedimentation in the Seawater intake (SWI) of the factory engine cooling system, accumulation of debris / plastic debris carried by the flow of water towards SWI and damage that has occurred in several parts of the TPPI Port breakwater building and is expected to continue to get worse. Plastic debris that is carried by the sea current from Tanjung Remen coastal waters so that some have accumulated around the SWI can cause high maintenance costs if the garbage and plastic are brought into the cooling system. Due to the all matters about the plastic debris, this study is expected to solve those problems. The purpose of this study is to simulate the debris at Tuban area and its surrounding by using MIKE 21 software.

2. Data and Method
This research was conducted in the area of Tuban waters in East Java Province, precisely in Tanjung Awar - awar shown in Figure 1. The coordinates of the locations of debris sampling are shown in table 2, where there are three locations to the west of TPPI Tuban, and one location is located to the east of TPPI Tuban.
Figure 1. The location of marine debris sample.

At location 1, which is closest to the TPPI Tuban’s sea water intake, it has the characteristic of predominantly plastic and styrofoam debris that is trapped around the coastal and sea water intake. The debris at location 2 is also dominated by plastics, but there are some wood litters. While at location 3, there are a lot of organic debris and noticeable activity of disposing garbage onto the beach by residents around the settlement.

Figure 2. Bathymetry mesh domain for hydrodynamic simulation using MIKE 21.
Figure 3. The marine debris accumulation at location 1.

Figure 4. The marine debris accumulation at location 2.

Figure 5. The marine debris accumulation at location 3.

Table 2. The coordinates of sample locations

| Location  | Easting  | Northing  |
|-----------|----------|-----------|
| West      | 598713.89| 9249346.26|
| East      | 608953.18| 9249840.90|
| Location 1| 604571.03| 9252858.55|
| Location 2| 603404.72| 9251917.39|

Input data for hydrodynamic modeling using MIKE 21 Hydrodynamic Flexible Mesh [22] required are tidal prediction data from Tidal Model Driver (TMD) [23] at one hour intervals during 2018-2019, bathymetry data (figure 2) from field surveys and the General Bathymetric Chart of the Ocean (GEBCO) [24] with 30-minute resolution, wind speed and wave height data from ECMWF (European Centre for Medium-Range Weather Forecasts) with interval time 3 hours during 2013 – 2018 (6 years) [13]. In addition, the coastline of Tanjung Awar-awar was digitized from Google earth 2018. The input data needed in the modeling of marine debris particle tracking is the amount of debris flux concentration at each source location that has been determined as a source of debris. Further data needed are the dominant types of debris and the percentage for each type of debris [25,26].

The results of hydrodynamic model, namely current speed and its direction will be used as a forcing of debris modelling using particle tracking module in MIKE 21. In particle tracking module, must be stated the quantity of debris volume in kg/second, settling velocity, and decay of the debris.
Table 3. The volume and mass of the litters based on the source [4].

| No | Source of litter          | Unit          | Volume (liter) | Mass (kg)  |
|----|---------------------------|---------------|----------------|------------|
| 1  | Permanent house /person/day | 2.25 – 2.50   | 0.350 – 0.400  |
| 2  | Semi-permanent house /person/day | 2.00 – 2.25 | 0.300 – 0.350  |
| 3  | Non-permanent house /person/day | 1.75 – 2.00  | 0.250 – 0.300  |
| 4  | Office /staff/day          | 0.50 – 0.75   | 0.025 – 0.100  |
| 5  | Store /staff/day           | 2.50 – 3.00   | 0.150 – 0.350  |
| 6  | School /student/day        | 0.10 – 0.15   | 0.010 – 0.020  |
| 7  | Secondary artery street /m/day | 0.10 – 0.15 | 0.020 – 0.100  |
| 8  | Secondary collector street /m/day | 0.10 – 0.15 | 0.010 – 0.050  |
| 9  | Local street /m/day        | 0.05 – 0.10   | 0.005 – 0.025  |
| 10 | Traditional market /m²/day | 0.20 – 0.60   | 0.100 – 0.300  |

Based on the results of interviews with the TPPI, the amount of the debris collected in the Sea Water Intake is as much as three sacks per day. Using the sack volume calculation (equation 1-9), the following results are obtained:

\[
\text{The sack volume} = \text{the area of base} \times \text{height} \tag{1}
\]

\[
= \pi \times r^2 \times \text{height} \tag{2}
\]

\[
= 3.14 \times 0.0625 \times 0.9 = 0.176 \, m^3 \tag{3}
\]

If it is considered that the compression of plastic waste in a sack of rice is half of the volume, then 0.088 m³. With the case of 3 bags of rice, then:

\[
\text{the volume of three sacks} = 0.088 \times 3 = 0.264 \, m^3 \tag{4}
\]

The density of plastic = \[ \frac{\text{mass}}{\text{volume}} \]

\[
\text{the mass} = \text{density of plastic} \times 0.088 = 13.6 \, kg \tag{5}\]

If it is considered that the density of the litter in TPPI Tuban is about 154 kg/ m³, then:

\[
\text{mass} = 154 \times 0.088 = 13.6 \, kg \tag{6}\]

Plastics and fabrics litter percentage calculation:

\[
\text{Plastics} \rightarrow 80\% \times 13.6 = 10.88 \, kg / \text{day} = 0.00012 \, kg / \text{second} \tag{7}
\]

\[
\text{Fabric} \rightarrow 20\% \times 13.6 = 2.72 \, kg/day = 0.0000314 \, kg / \text{second} \tag{8}\]

The method used in this simulation is simulation with the MIKE 21 particle tracking module [25, 26]. Before conducting the simulation using the MIKE 21 particle tracking module, the simulation was performed with MIKE 21 coupled hydrodynamics [21].
2.1 Settling Velocity
The particles accelerate until a constant velocity, called the terminal velocity, which depends on the particle size and described in Stokes’ Law [27].

\[ w_s = \frac{(\rho_s - \rho) \cdot g \cdot d^2}{18\mu} \]  

where:
- \( w_s \): particle fall velocity (m/s)
- \( \rho_s \): sediment density (kg/m\(^3\))
- \( \rho \): density of water (kg/m\(^3\))

2.2 Decay
Every particle of the substance or particle class may be exposed to decay. First order decay is included [27]:

\[ \frac{dM}{dt} = -k \cdot M \]

Where:
- \( M \): mass (kg)
- \( k \): decay rate (s\(^{-1}\))

3. Results and Discussion
Based on the results of the modeling, it can be seen that in the west season the marine litter accumulation in SWI is more dominant compared to the eastern season by 3.5 times (see the following table). As for the comparison of waste sources, during the west season the dominant litter originates from the western area with a proportion of 5.4 times that from the east. Whereas during the east season, the dominant litter originates from the east of TPPI, with a proportion of 2.5 times that from the west. The total weight of litter in the west season is 3 times more than in the east season. Besides in the west season, litter from the east is more dominant than from the west. Based on the tracking of the particles, litter originating from the east enters the SWI mostly through broken breakwater gaps.

![Figure 7. Reversed model particle tracking result using MIKE 21.](image)
Table 4. The marine debris mass in SWI is based on particle tracking modeling at every season.

| Season                          | Marine debris mass total (kg) | Marine debris mass (kg) From west | Marine debris mass (kg) From east |
|---------------------------------|------------------------------|-----------------------------------|-----------------------------------|
| Transitional 1 (15 April -14 May 2018) | 62.20                        | 0.00                              | 62.20                             |
| Summer season (August 2018)     | 100.84                       | 28.73                             | 72.10                             |
| Transitional 2 (15 Sept – 14 Oct 2018) | 100.34                       | 23.36                             | 76.98                             |
| Rainy season (December 2018)    | 349.14                       | 294.83                            | 54.30                             |

The results of the modeling of marine debris transport are shown in figures 8 – 15 with the color scale shows the value of surface elevation in each season. In the following figure it can be seen that in the transition season 1, the current direction is dominantly westward. This is consistent with the results of the amount of debris contained in SWI in the transition season 1, which is dominant from the east.

Note: (□: marine debris from the west and △: marine debris from the east)

Figure 8. The final result for marine debris transport modeling at transitional season 1.

Figure 9. The final result for marine debris transport modeling at transitional season 1 from the west and the east in sea water intake.

In the following figure, it can be seen that during the east monsoon, the current conditions are predominantly westward. The following figure shows that the solid waste from SWI in the east monsoon is dominantly from the east with a proportion of 2.5 times that from the west.
Figure 10. The final result for marine debris transport modeling at summer season.

Figure 11. The final result for marine debris transport modeling at summer season from the west and the east in sea water intake.

The following figure shows that during the transition season 2, the condition of alternating current is directed from east to west. Whereas the waste condition which is found in SWI during the transition season 2, is dominantly coming from the east.

Figure 12. The final result for marine debris transport modeling at transitional season 2 (September-October).
Figure 13. The final result for marine debris transport modeling at transitional season 2 from the west and the east in sea water intake.

In the following figure, it can be seen that during the west season, the current conditions are dominant towards the east. The following figure shows that the solid waste from SWI in the west season is dominantly from the west with a proportion of 5.4 times that of the east origin.

Note: (□: marine debris from the west and ∆: marine debris from the east)

Figure 14. The final result for marine debris transport modeling at rainy seasonal (December).

Figure 15. The final result for marine debris transport modeling at rainy season from the west and the east in sea water intake.

Research on the characteristics of marine litter on the west coast of Bali [27] was carried out using MIKE 21 hydrodynamics module software. Based on these studies, it was found that the current velocity in Kuta, Bali ranged from 0.05 to 1.75 m/s capable of transporting marine litter from the Bali
Strait and other sources during the Western season. The total of marine litter can be seen in Table 4, it shows that the marine litter reaches the highest amount when the west season (December – February).

3.1. The comparison of marine debris spreading in every design

Based on the existing conditions result, the amount of marine debris contained in the SWI is 13.6 kg/day. Using the calculation of the total population, finally the amount of marine debris flux obtained for sources from the west is 0.0057 kg/sec and from the east is 0.00504 kg/sec. The simulation of marine debris particle tracking for each design is shown in the table 5. Based on the results of the ten designs, design 5 has the least amount of marine debris that enters the SWI, which is 1.09 tons / year with a design effectiveness of 73.97% for the amount of waste in the SWI. The second sequence is design 3 with effectiveness against marine debris of 72.78%, then design 8 with effectiveness of 66.81%, and design 10 of 66.09%.

The table 5 shows the ratio of waste originating from a western source with an east source for each design. It can be seen from the ten designs that the dominant waste coming into SWI comes from the west of TPPI. The biggest difference between waste sources from west and east is to use design 1, which is 41%. But for design six, the amount of waste originating from the east is more when compared to waste originating from the west.

Based on table 5, it can be seen that the effectiveness of each design is greater to prevent waste coming from the west. The greatest effectiveness is seen in design 10, namely a reduction of 84.55% for waste originating from the west, while for waste from the east experiencing an increase of 8.43%. The visualization of marine debris track and its accumulation in seawater intake for design 1 to 10 are also shown by figures 17 -27.

![Figure 16. Every design for preventing the marine debris enter into seawater intake.](image-url)
Table 5. The total mass of marine debris in seawater intake, the effectivity of designs, and the design effectiveness comparison for the marine debris from the east and west direction.

| Condition | Total (ton/yr) | Effectivity (%) | West (ton/yr) | East (ton/yr) | Percentage (%) | Effectiveness (%) |
|-----------|---------------|-----------------|---------------|---------------|----------------|--------------------|
| Existing  | 4.188         | 3.3             | 0.83          |               | 80.3           | 19.70              |
| Design 1  | 1.47          | 64.81           | 1.04          | 0.43          | 70.48          | 29.52              |
| Design 2  | 1.84          | 56.02           | 0.98          | 0.86          | 53.19          | 46.81              |
| Design 3  | 1.14          | 72.78           | 0.76          | 0.38          | 66.23          | 33.77              |
| Design 4  | 1.50          | 64.18           | 0.80          | 0.69          | 53.33          | 46.00              |
| Design 5  | 1.09          | 73.97           | 0.65          | 0.44          | 59.63          | 40.37              |
| Design 6  | 1.74          | 58.45           | 0.65          | 1.09          | 37.35          | 62.64              |
| Design 7  | 1.54          | 63.23           | 0.54          | 0.98          | 35.06          | 63.64              |
| Design 8  | 1.39          | 66.81           | 0.61          | 0.78          | 43.88          | 56.12              |
| Design 9  | 1.57          | 62.51           | 0.77          | 0.79          | 49.04          | 50.32              |
| Design 10 | 1.42          | 66.09           | 0.51          | 0.9           | 35.92          | 63.38              |

Note: (□: marine debris from the west and △: marine debris from the east)

Figure 17. The final step for particle tracking marine debris with design 5.

Figure 18. The final step of marine debris in SWI and the comparison of easterly marine debris (left) and westerly marine debris (right) for design 5.
4. Conclusions
Based on the results of this study, MIKE 21 particle tracking module can be used to observe the movement of marine debris in the waters north of Tuban. The result shows that design 5 has the highest effectiveness value compared to other designs with a value of 73.97%. This means that the litter in SWI has been reduced by 73.97% for one year with a value of 1.09 tons/year. In addition, the percentage of waste originating from the west is greater than that from east origin, namely 0.65 and 0.44 tons/year with an effectiveness of 80.30% for waste originating from western sources and 46.99% for waste which comes from the east. Meanwhile, design 2 has the lowest effectiveness value when compared to other designs, which is 56.02%. Waste originating from the western source experienced a reduction of 70.31% while waste originating from the east experienced an increase of 3.89%.

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