Developing the Debris Incinerator Vessel as a New Solution for Managing Marine Debris in Small Islands of Indonesia

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Abstract. Marine debris has been considered a global environmental issue, yet its impacts on each country are varied. Indonesia as an archipelagic country comprises thousands of islands and vast marine territory. The marine debris has threatened many sectors, such as marine endangered species protection, coastal ecosystem, and human livelihood (e.g., sea transportation, tourism, fisheries). The government of Indonesia has implemented various efforts to address this marine debris issue, which include applying recent methods and prototypes from global partners. Based on these approaches, we learn that there are three key success factors to clean marine debris in a very large area of Indonesia, i.e.: good understanding of marine debris dispersion in Indonesian water, sufficient budget, and good coordination among stakeholders. Hence, the Marine Research Centre developed a prototype vessel design in 2021 to manage marine debris, particularly surround small islands, which in Indonesia is called “Kapal Insinerator Sampah” or Debris Incinerator Vessel (DIV). This vessel will focus on managing the waste generated by local inhabitants and marine debris stranded on small islands.

Keywords: Plastic Waste, ICZM, Small Island, Indonesia

1. Introduction

Marine debris has been considered a global environmental issue, yet its impacts on each country are varied. The main way of land-based debris into the ocean is through a river [1][2][3][4][5]. All of us agree with it intuitively and scientifically [1][2][6]. According to Meijer et al., [1], rivers in Asia contribute to about 80% of plastic waste emitted to the ocean. The plastic waste emitted to ocean through rivers contributes for 0.8 up to 2.7 million metric tons per year. Plastic debris in rivers, estuaries, and oceans will block fluxes of gas into and out of aquatic ecosystems. In the end, it will destroy ecosystem metabolism [3][4][7].

Indonesia is one of the Asian countries with unique features of rivers, wetlands, lakes, and dams. Kapuas is the longest river in Indonesia (1,043 km); Mahakam River is the busiest freshwater cruise line (with 900 km of length); Toba Lake is the biggest volcanic lake in Asia (3rd rank in the world); the world’s first three redundant dams on a single river are on Citarum, and also Merauke Wetland as the...
highest tide wetland in Asia.

Jambeck et al., [8] stated that Indonesia is the second-largest contributor for marine plastic debris through rivers and watershed areas. The government of Indonesia is aware of this reality. The awareness of the harmful impact of marine debris (MD) on the marine ecosystem has led to the establishment of Presidential Regulation no. 83 year 2018 regarding Marine Debris Countermeasure.

The impact of MD on marine endangered species, coastal ecosystems, and human livelihoods is huge [2][3][7][9]. According to Wilcox et al., [9], plastic litters is consumed by turtles, whales, and other animals. Coastal ecosystems such as coral reefs and mangrove forests also suffered from plastics litters [1][9]. Globally, it is estimated 52% of all sea turtles have ingested plastic debris [9]. In Brazil, 100% of surveyed turtles have ingested plastics [9].

Based on our survey in Karimun Java island in October 2020, plastic litters are stranded on the coast every rainy season (west monsoon), where its amount has exceeded the daily capacity of local environmental services in cleaning the area. Gordon [10] and Wyrtki [11] explained that during December-February when the west monsoon occurred, the surface current flow eastward in the Java Sea (see Figure 1). It is scientifically proven that the west monsoon drives the accumulation of MD stranded in the coastal area of the Karimun Jawa islands [10][11].

Action for managing marine debris (MD) in Indonesia is reinforced with the Presidential Regulation No 83 in 2018, where a National Coordination Team have been established. This inter-ministerial structure is act as political and strategical structure with a mandate to eradicate MD in Indonesia collaboratively, started from reducing land-based-debris (LBD) (www.sampahlaut.id) [6][12]. Afterward, a group at operational level called The Implementing Team was formed. The structure of this team can be seen in Figure 2.

There are five (5) strategies in combating MD. (1) National movement to increase the Stakeholders’ awareness. (2) Land-based waste management. (3) Waste management in the coastal and marine areas. (4) Funding Mechanism, institutional strengthening, monitoring, and law enforcement. (5) Research and Development. The target of these strategies is to reduce 70% of MD in 2025. All activities of MD countermeasure begin with managing LBD. Secondly, managing activities on seawater surface (tourism, fishery, oil and gas exploration, and transportation). To manage pollution from shipping activities, the Government has issued a regulation (Peraturan Pemerintah or PP) no. 21 year 2010 regarding the Maritime Environmental Protection. Once the debris enters the ocean, the cost of collecting and managing this debris will be very expensive while destruction has already occurred [6][12][13][14].

Indonesia is an archipelago with 17,504 islands scattered across the country. Many provinces and regencies consist of dozens to hundreds of islands. Administratively, there are 34 provinces and more than 250 regencies. Around 150 regencies have islands in their territory. Managing MD on the smaller island (especially small islands with an extent less than 100 km square) is different from the method in main islands. There are no big rivers, no lakes, and no dams, only small downstream and oasis. The origin of plastic pollution in small islands usually comes from residential, hotels, and resorts area, where tourism and artisanal activities are clearly a source of MD [15][16][17][18]. In addition, MD drifted by surface currents (monsoon season) and ocean gyre has contributed to the pollution of seawater areas in small islands [10][11][19].

This paper will assess the factual activities of LBD management in small islands including MD and make recommendations on technologies that can solve the problem. Research and engineering design activities have taken place since 2020 [15]. The study locations are in Seribu Island regency and Karimun Jawa in Jepara regency.
Figure 1. Oceanographic characteristics during east and west monsoon in Indonesia [10] (a) Surface current and sea-surface temperature (SST). (b) Chlorophyll distribution.

Figure 2. The Implementing Team according to Presidential Regulation no. 83/2018 regarding Marine Debris Countermeasure. (Source: https://sampahlaut.id/, by the Coordinating Ministry for Maritime and Investment Affairs of Indonesia).
2. Methodology

2.1. Survey on Factual Activities

In Seribu Island, most of the waste is used for reclamation. The operational model for reclamation is to fill the target area with wastes until 85-90% then finally covered it with soil. This method is applied to save costs, also getting new assets easily for residents (see Figure 3.a).

The local government has developed 3R (reduce, reuse, recycle) center in this island, known as “Bank Sampah” (in Bahasa) or Waste Bank (see Figure 3.b) The activities at Bank Sampah include the composting process, diesel, and electrical incinerators, waste carrier vessels, and occasional activity of beach clean-up programs. Bank Sampah is a method for recycling item for cash, by using bank account provided by NGOs (private sector). Usually, they collaborate with extended program responsibility (EPR) of the big companies such as Unilever.

Another method to process waste is by using an electrical incinerator machine (see Figure 3.c.) with a maximum burning temperature of up to 150°C. The quantity of waste that can be processed per cycle using this machine is considered very low. There are 5 incinerators operational, while other 11 located near the waste bank are not operated after receiving complaints from the resident. They consider the smoke and odor from incinerator machines are deadly to human health.

The local government of Seribu Island also operated 28 waste carrier vessels, with a capacity of 125 tons and 8 tons (see Figure 3.d. and Figure 3.e.). The 125-ton vessel only has a maximum speed of 4 knots, due to poor initial design and poor fabrication process. The Director for Environmental Service of Seribu Island Regency informed that the fuel cost for operating these vessels is around 4 billion Rupiahs (about USD 260,000) per year, excluding maintenance costs and crew salaries.

The waste/debris that has been collected in Seribu Island is then transported to mainland Java and transferred to Muara Angke port in Jakarta (see Figure 3.f.), where this transfer process has a high possibility of leaking waste into the sea. The government operates 1 to 2 vessels to transport the waste from Seribu Island per week, depending on the holiday season. Sometimes, between December and February (during the rainy season), all vessels cannot sail due to high waves and strong winds.

This might be the longest waste trip in Indonesia, even in the world, where the distance between the islands to the terminal dumpsite is approximately 160 km or 100 miles. The waste is transported using carrier vessels to the terminal dumpsite of Bantar Gebang because it cannot be processed on the island. The average waste production is 10-50 tons per week depending on the number of tourists visits the islands (see Figure 4.a).

The Karimun Jawa Islands has applied a similar LBD management approach to the Seribu Islands but without waste carrier vessels (Figure 4.b.). Based on an unofficial source, the local official plans to use vessels to transport the waste to mainland Java. Karimun Jawa islands subdistrict has 3 km² mangrove forest, 27 islands, 13 km² tropical lowland forest, and 1,101 km² sea.

Waste bank and plastic trash shredder & compactor facilities have been established in the Karimun Jawa islands. However, the main problem is managing stranded plastic debris in the coast and mangrove forests, especially during the west monsoon or rainy season [10][11][20]. Marine Debris (MD) will also affect seaweed cultivation, ecosystems, maritime transportation, and tourism activities [21][22][23][24].
2.2. Engineering Design Process

A ship is designed to fulfill the following services: (1) specific requirements of the owner or a mission of authority or society; (2) disposal of certain functional characteristics, specific hull form and powering, space, and weight distribution; and (3) demonstrating certain technical and economic
performance [25][26]. Papanikolaou [27], Martin [28], and Wijnolst & Wergeland [29] define the importance of the two aspects in designing a ship, i.e., technical and economic performance. The main economic aspect in designing a solution for MD management in Seribu Regency is to minimize fuel cost (US$ 260,000 per year). In the Karimun Jawa regency, waste vessels are required due to insufficient open areas for managing LBD on-site and the abundance of stranded plastic litter in coastal areas during the west monsoon. Since the ship will be used by the local government of Seribu Island and Karimun Jawa, the economic performance of the ships, e.g., low fuel consumption becomes the main consideration.

Jones [14] explained that the economic aspect should integrate human society with its natural environment for sustainability. The engineering activity is one part of economic aspects that should consider sustainability. Designing the Debris Incinerator Vessel (DIV) is a consideration for sustainable economic activity.

![Figure 4](https://www.google.com/maps)

**Figure 4.** (a) The Seribu island's debris trip (around 160 km) to the final dumping area in Bantar Gebang, Bekasi, West Java province. (b) The Karimun Jawa islands distance (around 70 km) to Jepara regency capital city, Central Java province (Source: [https://www.google.com/maps](https://www.google.com/maps)).

The technical problem of the existing debris carrier vessels is that the maximum speed is only 4 knots. These vessels are also unable to sail during the west monsoon when the wave is high, and the wind condition is strong. Poor performance of 125 tons capacity debris carrier vessel should be a good indication of flaws in the ship design process and protocol (Figure 5.a. and Figure 5.b.) Many incidents have happened due to flaws in the ship design process and protocol. In the end, it will cause operational costs as well. Designing and planning a ship is not the same as designing custom cars or motorcycles. The ship design process must pass many looping procedures [27][28][29][30]. The filters are (1) the ship’s technical parameters, (2) economical operating costs [26], (3) sounds good for investment and financing, (4) fabrication aspects. These filters will be looping many times until all filters are fulfilled.

3. Result and discussion

The first step, the important thing to do in general is to determine the operation area of the ship, i.e., depth, height, and wavelength parameters. In this case, the parameters are the Java Sea conditions. Next step, determining the main dimensions of the ship (overall length, width, height, and depth of the ship).

The third step is to make ship lines plan as well as various allocations and calculations of space, construction, and finally, the amount of resistance and ship power requirements (based on the speed and
propulsion) for various cargo weights (colon ships to full load), while still meeting stability and airworthiness of the ship. The work is quite complicated and requires experience [27][28][31].

The calculation of the ship's resistance is carried out using the Holtrop method through Maxsurf Resistance software. As for the DIV ship, assuming the main dimensions of the DIV above and a cruising speed of 8-10 knots, the prediction of the ship's resistance with the Holtrop method is around 34.1 kilo Newton (kN). In the calculation of the ship's main machinery requirements, the DIV calculation is based on the calculation of the EHP (Effective Horsepower) of the operational speed in meters per second (m/s).

The next step is to estimate DHP (Delivered Horsepower) and BHP (Brake Horsepower) by inserting additional figures operations known as sea-margin (rerouting, the toughest weather conditions) of about 15 percent. The above calculation can be used as a parameter to select the main engine to calculate the Engine Propeller Matching. It is being calculated to obtain the level of efficiency of the main engine with power capacity. For DIV, the engine capacity is around 485 kW or 650 HP.

3.1. Selection of Propeller (propeller drive)

The selection of the DIV propellers is made based on three important things. The first is the fulfillment of the maximum height requirement of the propeller. Second, the highest level of propeller efficiency can be achieved. The final is preventing cavitation potential with acceptable levels by the propeller installation location (The aft construction as well as the distance to steering blade). Here are the propeller types:

- Type : B3-85
- Db (diameter) : 1.98
- P/Db : 0.85
- Efficiency : 0.49
- N (revolution) : 273 RPM

3.2. Calculation of empty weight (Light Weight Ton, LWT), maximum weight (Dead Weight Ton, DWT)

Empty ship weight (LWT) is one of the important parameters in designing a ship. In calculating LWT there are three main components, namely: the weight of the ship's steel, the weight of the ship's equipment, and the weight of the ship's machinery. In calculating the LWT design, we use the calculation estimation method [25][31][32], where the resulting number is an estimated number obtained from known parameters. The LWT for DIV is 326.3 tons.

The calculation of DWT (Dead Weight Tonnage) is a parameter that estimates various components of the ship's load including its cargo. This includes the weight of the main engine, main engine fuel, the weight of the auxiliary engine and auxiliary engine fuel, weight of lubricating oil, the weight of freshwater needed for engine cooling needs and domestic needs of crew members, the weight of food, the weight of crew and luggage, and other recommended weights. Through various calculations in shipbuilding design procedures [25][31][32], it is estimated that the DWT is around 545 tons.

3.3. Calculation of the weight of the ship's tanks

The ship's ballast tank is designed for the ship's stability function. The capacity of the ballast tank ranges from 10-20% of the ship's displacement weight. Therefore, the volume of the ballast tank in DIV ranges from 85m$^3$ to 170 m$^3$.

The fuel tank is determined based on the fuel required by the owner, which is 20 tons. Here are some things that need to be considered in determining the duration of the DIV sailing: (1) the amount of fuel, (2) the fuel consumption of the main engine (M/E). If these two data have been obtained, it can be calculated to determine the duration of sailing. Fuel Consumption 120 l/h or 2880 l/day, 2,880 m$^3$/day. Total fuel is 20 tons assuming a fuel tank with a volume of about 22.2 m$^3$, the result is the sailing duration of the ship is up to 7 days.
Freshwater tanks are determined based on the amount of freshwater needed in the vessel, which is one of the most important requirements in DIV. Some of the uses of fresh water on ships are for sanitation and engine cooling system. According to the calculation of LWT & DWT, it can be seen the minimum capacity of freshwater required by DIV to operate for the duration of sailing. The need for freshwater is around 13.2 tons.

3.4. Ship Stability Calculation

In carrying out the DIV design processes, it is necessary to calculate the stability of the ship. Maxsurf stability application/software is used to estimate the stability of DIV. There are two calculations to be performed on Maxsurf stability, namely Upright Hydrostatic & Large Angle Stability. In performing these calculations, the criteria to be used are IMO A.749(18) Code on Intact Stability.

Before doing the calculations (using Maxsurf software), several things need to be prepared so that the stability calculations can run smoothly. The first thing to do is to record all kinds of equipment and machinery weight and position. This data is then entered into the Maxsurf Stability device load-case. In this calculation, two types of load-cases are made, namely on a full load and on an empty load.

After the data from the two conditions are entered into the load case, the tanks are placed according to the positions described in the general design. Two important parameters are analyzed in assessing the stability of DIV during the process of loading and unloading debris and other operating processes at sea, namely:

1) Upright Hydrostatic; is an analysis used to determine the characteristics/ hydrostatic properties of ships. Before analyzing a hydrostatic model of the ship, several settings include trim, draft, and displacement must be made.
2) Large Angle Stability; Large angle stability is the stability analysis/balance board, which allows the user to define the parameters of hull hydrostatic-based heel angle and free to trim. Before analyzing the stability of the angle of the ship models, several arrangements include heel, trim, waveform, hog and sag, and laden ship operation criteria must be made. The result can be seen in Figure 5.c.

After finishing all the steps above, we have the principal dimension of the DIV. Through the various design processes mentioned above, the main dimensions of DIV in the first cycle are planned as follows:

- LOA (Length overall) = 48.3 m
- B (breadth) = 10.8 m
- T (draft) = 2.5 m
- Crew = 17 person
- Hull without bulbous or X-bow

After going through several design cycles (about 4 cycles), a general plan for the arrangement of DIV spaces is produced (not be shown due to the Patent process).
The 3rd International Conference on Maritime Sciences and Advanced Technology

IOP Publishing

IOP Conf. Series: Earth and Environmental Science 925 (2021) 012016
doi:10.1088/1755-1315/925/1/012016

Figure 5. (a) The working process between science and engineering (picture concept source: H Chandra). (b) The vessel design looping processes to get into the final specification or detailed engineering design [24]. (c) Large Angle Stability curve. (d) Debris Incinerator Vessel (DIV) rendering picture and is undertaking the patent process.

The recommendation for managing LBD and stranded plastic debris in small islands is by using a Debris incinerator vessel (DIV). Following are some benefits of using DIV instead of sending the debris to Bantar Gebang (final dumping area in Bekasi, West Java province):

- The incinerator capacity is 4-5 tons per day
- The incinerator fulfills the Environmental Ministry Regulation.
- DIV will save fuel costs USD 260,000 per year.
- No land utilization in the small/conservation islands.
- DIV is undertaking a patent process in Indonesia.
- Investment cost around USD 850,000

In this year of 2021, our team is working on the DIV design with an investment budget of around USD 110,000 and the target is to establish a prototype in 2022 or 2023. We hope this initiative could be mainstreamed into a nationwide program for eradicating MD and can be scale-up further with international support.

4. Conclusion

Reducing and managing LBD (land-based debris) is a vital aspect to minimize leakage into the ocean that will become MD (marine debris). LBD awareness campaign, research and development, stakeholders’ collaboration, and financial support also support Indonesia’s program for a 70% reduction in MD by 2025. For small islands characteristics which are many in Indonesia, we recommend utilization of Debris Incinerator Vessel (DIV) in managing MD on site. The DIV will save time, no open area required, and saves fuel costs for transportation. Utilizing economic and ecological aspects in engineering is a way for maintaining the sustainable use of our environment. Eventually, it will benefit human society.

Acknowledgment and author statement

This research is funded by the Marine Research Centre, The Agency for Research and Human Resource, Ministry of Marine Affairs and Fisheries Republic of Indonesia, under fiscal year 2020 and 2021. H Chandra and D S A Sianturi have equal contributions in writing this manuscript.
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