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バージョン：

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Abstract: Environmentally friendly fuels are increasingly becoming a binding necessity along with policies to reduce global emissions. Natural gas is a promising fuel for marine transportation. The small-scale LNG carrier is one of the carrier ships designed for distributing natural gas in inland and shallow waters. The purpose of this study is to determine the optimum dimensions SSLNG with three parametric designs of cargo load conditions, i.e., 2500 m^3, 5000 m^3, and 7500 m^3. The spiral design theory has been used to optimize 3 particular parameters of ships, i.e., volume, mass, and linear dimensions. The design criteria is determined based on the statistical data from existing small-scale LNG carrier dimensions from all over the world. As a case study, two shipping destinations were used to supply power plants in remote areas with shallow water conditions. The result of optimum dimension from the analytical approach obtained the main dimensions of small-scale LNG carrier 2500 m^3 are length overall 81.5 meters, beam of 14.2 meters, and draught of 4.8 meters. This optimum ship dimension is suitable for serving shallow water conditions. Further findings in this research are that the dimensional ratio criteria for small-scale LNG ships vary depending on the cargo volume to be designed.

Keywords: Natural gas; marine transportation; ship design; parametric design; shallow water

1. Introduction

The need for electrical energy has become a basic need in this millennial era. This has resulted in power plants in various regions requiring more electricity supply[1)]. The source of electrical energy that is claimed to be more environmentally friendly[2)] and the future power plant aim to be higher efficiency[3)] is the use of liquefied natural gas (LNG) as an energy source for electricity generation[4)]. However, not many power plants use gas as their main fuel, especially in developing countries like Indonesia[5)]. Some of the factors that become constraints in the use of gas as the main fuel, one of which is economic factors, and the supply-demand system does not reach all existing regions[6)].

At present the supply-demand system for inter-island LNG needs is still dominated by very large vessels, small-scale transportation is still very rarely used[7)].The recent development of ship building has built in eco shipyard industrial park[8)], some countries that have developed SSLNG are Norway and Japan[9)]. The application of LNG distribution using SSLNG in the world is still relatively rare. In 2016, only 57 SSLNG units with an average capacity of 13000 m3 existed in the world and some were still under construction[10)]. This shows the use of small-sized LNG vessels is still relatively new and becomes a great opportunity in the development of knowledge[11)], especially in the field of marine transportation[12)].

SSLNG is a natural gas transport vessel in a small capacity. Ship capacity included in the Small-Scale LNG category is having a maximum capacity size of 40000 cubic metric[13)]. SSLNG is very suitable for the conditions of the region which has many islands[14)] and the distribution of gas power plants with a small capacity[15)]. The use of SSLNG was chosen because of consideration of the geographical condition of the port which has shallow depth, so it is not possible to use pipelines[16)]. The use of LNG as a fuel is also considered environmentally friendly[17)], less carbon emission[18)] and can be applied to existing engines by converting it to a dual fuel engine[19)] and retrofit engine[20)] as well as development of retrofit dual fuel engine[21)]. Current development of ship technology use passive and active control to obtained more energy efficiency[22].

Based on existing literature studies, the problem statement that can be taken is how the influence of changes in the dimensions of the ship to the loading capacity of the ship's hull SSLNG that can meet all the criteria from a database of existing ships. The purpose of this study is to calculate the most optimum SSLNG main dimensions by determining design parameters in accordance with predetermined criteria. This hull parameter is used to optimize the design of the hull based on the availability of an existing SSLNG hull design with a variable is load capacity. This optimization is intended for the size of the main dimensions of the ship to be changed, namely length (*L*), width (*B*), water-laden (*T*), and height (*H*) to the specified variable load value.

2. Research Methodology

2.1 Parametric design of ship dimension

In designing the ship structure, it requires a series of special stages. The initial stage of shipbuilding is the design of ship design, where the design process is carried out. In general, the series of stages in ship design can be seen in the spiral design theory. The design process starts from determining the purpose of the ship itself, making the design concept, feasibility analysis, to forming a full design[23].

There are 3 prime parameters obtained by determining the first estimate of the ship size to be made, namely volume, mass, and linear dimensions. One of them will dominate the choice of ship size to carry the required cargo. Volume is related to the percentage of the total distribution of contents from the ship. The mass is related to the weight of the heavy loads and other components on the ship[24]. While the linear dimension is related to the minimum dimensions determined from the dimensions of the charge carried. From these prime parameters, the design can be determined using parametric studies that discuss the dimension ratio and hull coefficient. The dimension ratio is very important, because from this ratio it can change the main dimensions of the ship, where each ship has special features on the shape of the hull to distinguish one from the other depending on the function and purpose of the ship being built. Dimension ratios include *L/B*, *B/T*, and *T/H*. Ships that have a significant *L/B* ratio value have more excellent maneuvering characteristics. Meanwhile, a small *B/T* ratio will provide good stability characteristics.

As for the hull coefficient, what is meant is the beam coefficient (*Cb*), the waterplane coefficient (*Cw*), the perismatic coefficient (*Cp*), and the ship's middle cross-section coefficient (*Cm*)[25]. The beam coefficient is the ratio between the volume of a ship immersed in water and the volume of the beam. The waterplane coefficient is the ratio between the area of a waterline in a water laden with a square area limited by the length and width of a ship[26]. The prismatic coefficient is the ratio between the volume of the hull located below the surface of the water and the volume of the cylinder[27], where in the midship cross section and the length[28]. The center cross section coefficient of the ship is the ratio between the middle cross-sectional area of the ship with a square area limited by width and water-laden.

The parametric design of the ship was developed after the formation of a number of ships of the same type but having one parameter in common[29]. The similarity of these parameters makes the designer to design ships with parametric design methods based on previous data which will then be further developed and optimized[30]. By using this approach, changes in the shape of the hull are more easily achieved, because when the designer changes one parameter, the other is parameterized, so it can automatically be actualized[31].

2.2 Parametric design of ship hull

One of the parametric design methods is the overall sizing strategy[32]. This method used in determining the initial size (preliminary sizing) will vary depending on the type of ship chosen[33]. In this method, each design must be able to strike a balance between the ability of the ship to carry the weight and the volume of the load. In this case there are 2 that must be chosen namely between weigth limited or volume limited. If the selected weight is limited, the main size can be controlled by equation (1).

$$\Delta = \gamma \times L \times B \times T \times C_b \times (1 + s) \qquad (1)$$

Where Δ is displacement, γ is the density of water, L the length of the ship, B the width of the ship, T is ship draught, C_B is the beam coefficient, and s is the shell appendage allowance. This weight limited model parameter can be used to estimate the total weight component of the ship. Determination Δ can also use equation (2).

$$C_{DWT} = \frac{DWT}{\Delta} \qquad (2)$$

Where DWT is deadweight tonnage and C_{DWT} is the coefficient of deadweight tonnage. If volume is limited, the main measure is controlled by equation (3).

$$\nabla_U = \{L \times B \times H \times C_{Bh.} \times (1 - \sigma)\} - \nabla_{LS} - \nabla_T \qquad (3)$$

Where ∇_U is the load volume, H height of the ship, beam coefficient at full depth, σ structure allowance, ∇_{LS} the volume of the ship with machining equipment and other light ship weight components, and ∇_T the volume of the hull with fuel, ballast, water, and another tank.

3. Case Study and Data Inputs

3.1 Remote island and shallow water draught

The location chosen for this study is the northern Sumatra region specifically for Sabang and Nias Island, with Arun as the main supply for both regions. The choice of locations for Sabang Island and Nias is because these two regions have little electricity needs in remote areas. Nias Island needs gas for mobile power generation at 320.62 m3/day while Sabang Island at 41.22 m3/day. In addition, the two regions have a shallow water draught port so that they are not affordable by large vessels. The route distance is determined using the sea distance calculator, as seen under the ship's distance as far as 507 NM shown in Fig. 1.

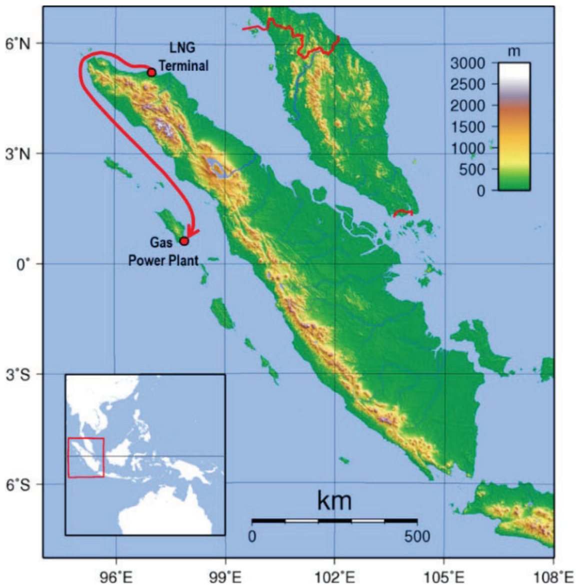

Fig. 1: The shipping route of small-scale LNG carrier

The use of SSLNG vessels is more effective than using a pipeline distribution system. In addition, it facilitates loading activities directly into storage without having a regasification system, because if you use a pipeline distribution system, you must pass the regasification system to convert LNG loads in liquid to gas so that it can be easier to distribute in the pipeline. From an economic perspective, the use of Small-Scale LNG Carriers is more economical compared to pipeline distribution systems. In addition, the location and geographical condition of the port which has shallow waters is very effective when using a Small-Scale LNG Carrier because of its small draft, which is under 5 meters, thus allowing this ship to lean directly on the relevant port.

3.2 Ship Comparison Data

After determining the shipping route and the location of the distribution of LNG gas supply, the main dimensions of the ship are determined. Researchers collected data on 44 small LNG ships that already existed from a range of 1100 m3 to 30000 m3.

4. Result and Discussion

4.1 Estimation of Particular Dimension

After determining the shipping route and the location of the distribution of LNG gas supply, the main dimensions of the ship are determined. Researchers collected data on 44 small LNG ships that already existed from a range of 1100 m3 to 30000 m3. From the comparative ship data obtained, then made regression graphs and line equations for the main dimensions of the ship. The equation of the load capacity line to the main size is shown in Fig. 2, 3, 4 and 5.

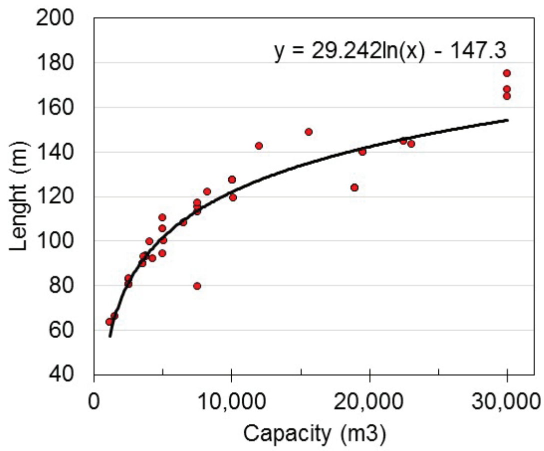

Fig. 2: Line equation between the load capacity and ship length

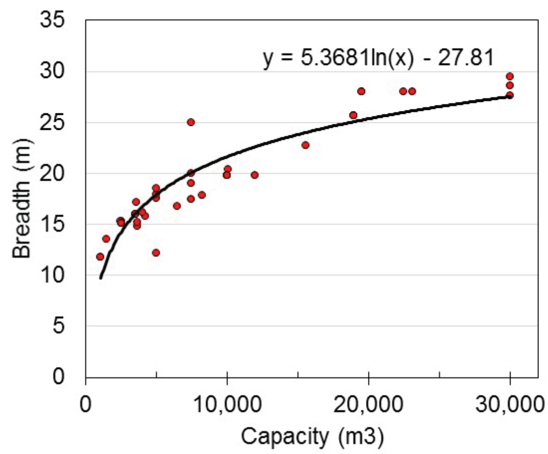

Fig. 3: Line equation between the load capacity and ship breadth

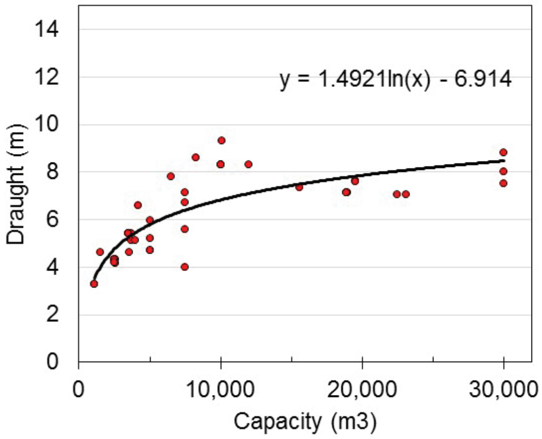

Fig. 4: Line equation between the load capacity and ship draught

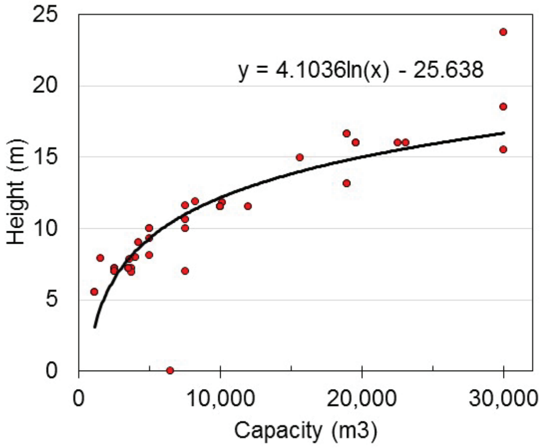

Fig. 5: Line equation between the load capacity and ship height

Figure 2 shows the line equation between load capacity and ship length. Figure 3 shows the line equation between the load capacity and ship breadth. Figure 4 shows the line equation between load capacity and ship draught. Figure 5 shows the line equation between the load capacity and ship height. From the graph we have obtained the power line equation with the variable x as the load capacity and variable y as the main dimensions of the ship being sought, so we get the main dimensions of the ship shown in Table 1.

Table 1. Principal dimension of SSLNG.

Principal Dimensions	LNG Capacity		
	2500 m^3	5000 m^3	7500 m^3
Length (m)	81.5	101.8	113.6
Breadth (m)	14.2	17.9	20.1
Draught (m)	4.8	5.8	6.4
Height (m)	6.5	9.3	11.0

4.2 Dimension Ratio of Ship Dimension

The ratio of the main dimensions of the ship is the ratio between the size of the main dimensions with the size of other main dimensions to meet the classification standards of certain types of ships, and the aspect ratio of these dimensions is used as a benchmark in determining the size of the ship according to the type of ship to be made based on existing vessel size data. The ratio of the main dimensions of the ship is related to the length of the ship and the transverse strength of the ship, stability, and of course the load capacity that can be transported. The main dimensions of the ship include *L/B, B/T, T/H,* and *L/H*. This dimension ratio value will certainly be related to the condition of the ship's strength, stability[34], and has affect to the ship maneuvering[35]. Dimension ratio criteria for Small Scale LNG Carriers are shown in Table 2.

Table 2. Examination of dimension ratio of SSLNG

Dimension ratios	Ship Capacity			Criteria
	2500 m3	5000 m3	7500 m3	
L/B	5.74	5.68	5.66	3.18 – 7.75
L/H	12.60	10.93	10.35	7.09 – 13.5
B/T	2.98	3.09	3.14	2.07 – 6.25
T/H	0.74	0.62	0.58	0.32 – 0.79

From the determined dimension ratio of SSLNG, the ship characteristic can be observed. The greater the *L/B*, it will increase speed, more load space, good stability (during high-speed conditions). However, it is difficult to maneuver because it is too far away, and it is also important to consider the elongated strength of ships that are vulnerable at the 40% Lpp section at midship. *B/T* relates to the transversal stability of the ship and the rolling period of the ship, therefore *B/T* is smaller has good stability[36]. *L/H* is related to the lengthening strength of the ship, just like the *L/B*, if the *L/H* value is greater than the strength construction in the middle of the ship must also be considered more. For *L/H* related to the stability of the angle of the ship. Between these parameters, the most important of the dimension and ratio depend on the objective function of the ship designer.

5. Conclusions

Research on the design of the hull parametric design of load capacity on small scale LNG carriers has been carried out, from the analysis that has been done it can be concluded that there are three ship sizes that can be parameterized based on the loading capacity of 2500 m3, 5000 m3 and 7500 m3. The optimum ship lengths of the three ship sizes are 81.5 m, 101.8 m and 113.6 m, with draft ships being 4.8 m, 5.8 m, and 6.4 m, respectively. By looking at water depth conditions at LNG receiving ports in remote areas, 2500 m3 vessels are suitable vessels for serving waters with shallow water conditions. From the results of this study directing future research that is making detailed designs that include general arrangement and optimum speed for each of these sizes, so that in the end an economic analysis can be calculated from the construction of the ship.

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