Conceptual design of the LNG dual-fuel system for harbour tug towards Indonesia Greenport

A Z M Fathallah¹, I M Ariana¹, G H Putra¹ and B Ma’ruf²

¹Marine Engineering Department, Faculty of Marine Technology, Sepuluh Nopember Institute of Technology, Indonesia
²Badan Pengkajian dan Penerapan Teknologi (BPPT), Indonesia

Email: fathalaz@its.ac.id

Abstract. Declaration of several large ports as Greenport indicates that increasing the environmental concern of port operation in Indonesia. Harbour tug as one of the port’s operational supports is also required to contribute low emissions. One method to reduce exhaust emissions from tugboats is to replace the use of fuel oil with natural gas. This study describes the conceptual design of a dual-fuel LNG system at the harbour tug vessel for operational needs at the Indonesian port. The 2x2500 HP Harbour Tug, which is the case in this study, uses a dual fuel diesel engine as a prime mover with a direct mechanical propulsion system. Study optimization considering the operational mode of a prime mover will determine the LNG storage capacity, due to harbour tug vessel operation and space capacity as well as of bunkering system. The design parameters for the main components of the fuel system, such as the Regasification Unit, Gas Valve Unit are essential considerations to support the system’s operation optimally.

1. Introduction
The government, through the Coordinating Ministry for Maritime Affairs, has conducted socialization regarding Greenport in Indonesia [1]. The Environmental-Friendly Port Management Policy also emphasized by the Directorate General of Sea Transportation, which called Ecoport [2]. This policy is considered necessary besides referring to sustainable development, especially a clean port movement. It is not only the area have to clean, but also the area must be supported by aspects that synergize with the port operation, including tugboats.

The tug ship consists of various kinds, one of which is the harbour tug. This ship is a multipurpose ship with good performance capabilities, which is it used to guide mooring operations. Besides, this harbour tug ship is also a fire fighting, oil spill response and ice-breaking [3]. Harbor tug is a ship that contributes to emissions in the port environment. The performance of the propulsion engine which is capable of producing a large amount of power with an effective level of 50% and with the operation mode that often changes is one of the reasons for higher fuel consumption and emission production [4]. Then many innovations have been made in reducing high emissions, especially sulfur content (SOx), nitrogen content (NOx), particulate matter (PM) and carbon footprint [5].

LNG fuel is one of the innovations that developed to reduce the high content of fuel emissions from ship operations. This fuel including in the low flashpoint, has been widely used in various types of ships, for instance, the tugboat. The results of the combustion of diesel engines using LNG fuel are considered capable of reducing sulfur levels (SOx) and nitrogen levels (NOx). Moreover, the availability of LNG reserves is still quite large compared to oil reserves [6]. The LNG fuel development will be applied to this study, in which conduct the design of harbour tug 2x2500 HP. This process including selection and
design of fuel transfer system, LNG storage tank, regasification unit, gas valve unit and bunkering system.

2. Methodology

2.1. Operational Mode Criteria

Operational mode criteria determine the parameters design of the fuel transfer system for the harbour tug, which includes all activities at a port. For tug operation, this criterion will be determined by the workload differentiation. The heavier the workload, the engine will still work, and fuel requirements will also increase. Research conducted by [7] is one of the operational mode selections. There are several modes, such as free-running, ship assist/tugging and emergency. When the engine is turned on, off as well as an emergency, the engine will use diesel mode. As for the cruising/normal operation (free-running and tugging), it will use the gas mode. Optimization is carried out to keep the air intake towards the fuel ideal in gas mode despite a rapid increase in load. [8] conducted the other operational modes criteria for harbour tugs was moored at quay, transit, and assist. That mode will often take turns happening, but usually, the assist mode only happens for a concise duration because the pulling of the ship only in a short time, but determining the total power required for each mode is the most crucial aspect of the design of a harbour tug. The operational mode changes between transit, stand-by and moored have different power, in which it will affect the quantity of fuel needed.

| No. | Average Operational Working Distribution | Fuel Mode |
|-----|------------------------------------------|-----------|
| 1   | Starting Engine                          | Diesel Mode |
| 2   | Free Running                             | Gas Mode   |
| 3   | Tugging                                  | Gas Mode   |
| 4   | Emergency                                | Diesel Mode |
| 5   | Stopping Engine                          | Diesel Mode |

Depend on the ship’s duties and the distribution of the ship’s load, the operational mode determined according to the references above. The 2x2500 HP harbour tug will be applied in Indonesian ports with an operating time of 14 hours per day. This ship will perform the core task of tugging. The operational mode that is applied can be seen in the table above.

2.2. Diesel Engine and Its Characteristics

The combustion of the dual-fuel diesel engine is determining into several kinds, for instance, type of fuels, engine’s power and engine’s durability [9]. Not only has stated before but also the method of mixture preparation, combustion chamber design, method of load control, engine emission, also operating characteristic [10]. The divide type of fuel seen based on the type of raw material, one of which is fuels from natural gas. These fuels include compressed natural gas (CNG) and liquified natural gas (LNG). LNG has well characteristic, especially antiknock. It offers higher thermal efficiency and lowers specific energy consumption [11]. Nevertheless, [7] conducted research using the dual-fuel diesel engine applied for the tugboat. Changes in fuel consumption are affected by changes in engine operating modes. In the other side, changes rapidly of the operational mode will give poor performance due to not sufficient air supply, which operated by the turbocharger. However, it solved with take the technical approach and succeeded in developing a dual fuel engine suitable for propelling tugboats called the z-peller.

The fuel consumption is an essential aspect determining a dual-fuel engine. Related studies have shown that levels of fuel consumption vary with load. Under loads from 25% to 75%, the share of natural gas increases slightly, and the maximum value is 85.4% at 75% load. This result occurs because under this load, the AFR is within the normal range, and then, the mixed gas burns completely. When the load condition is greater than 75%, the share of natural gas sharply decreases. Under high and full load, more fuel consumed, and the mixed gas is too rich to be wholly burned [12].
One alternative application to dual-fuel diesel engines to improve performance is the high-pressure common rail injection technology. In addition to increasing the fuel/air mixture ratio, this system is also able to increase combustion by reducing NOx and PM emissions [13]. However, research conducted by [14] shows that the use of a high-pressure dual-fuel diesel engine which requires high pressure has a drawback, namely that the gas mode must be changed to diesel mode when the load is low 15-20% to keep emissions within range.

Then, the LNG fuel transfer system on ships divided into several methods, for instance, LNG transfer within the pump, LNG transfer within the pressure built-up, and LNG transfer within the compressor. First, the LNG pressure required by the dual-fuel diesel engine approximately 6 to 8 bar, in which the system uses a submerged pump. Second, the rising of pressure tank complying to the engine’s requirement will use a pressure built-up design concept. In fact that by the time, the tank pressure will get smaller, encourage the PBU to activate so the tank will quickly reach maximum pressure. Third, the LNG fuel that flowed using a compressor increases the temperature, so an inter-cooler and after-cooler installed to keep the gas temperature within limits that are acceptable to the system.

2.3. LNG Storage Tank

The use of LNG as harbour tug fuel in Indonesia is still few even though this fuel is one of the lower emission productions like sulfur (SOx) and nitrogen (NOx) contents. In this study will conduct the design of LNG storage tank for a harbour tug 2x2500 HP. Due to the fuel is natural gases, the design will use a cryogenic tank, which requires special storage at shallow temperatures to keep them in a liquid state. The LNG tank selection parameters in this project are the design and placement of tanks, tank components, and evaluation of tank materials. All tank criteria are interrelated, for example, a tank that has a high-pressure design will require a strong material so that it can withstand this pressure.

The standard storage system for transporting various liquid hydrocarbons at low temperatures for decades according to IGC (International code for the construction and equipment of ships carrying liquefied gases in bulk) one of which is a C-type tank/pressure vessel. The are many aspects to compare the LNG storage tank selection.

| Indicator                              | Pressure Vessels Single Walled | Pressure Vessels Double Walled | ISO Tank                      |
|----------------------------------------|--------------------------------|--------------------------------|-------------------------------|
| Capacity Range                         | 600 -2500 m³                   | 30 - 1000 m³                   | 20 - 40 m³                    |
| Pressure Range Material                | 4 – 6 Bar                       | 7 – 9 Bar                      | 6 - 15 Bar                    |
| - Austenitic stainless steel, 9% Ni steel and Aluminium alloy | - Austenitic stainless steel or 9% Ni steel and Aluminium alloy | - Austenitic stainless steel or 9% Ni steel and Aluminium alloy |
| The flexibility of operation, security also safety | - All pipe connections above the maximum liquid level. | - Class acceptance of bottom pipe connection. | - ISO containerized LNG tank, specifically designed for marine applications. |
|                                       | - Polyurethane insulation.      | - Layer Insulation (MLI) / Vacuum. | - Every container is docked in a dedicated “docking station”, designed for multiple, horizontal and vertical stacked container arrangements. |
|                                       | - Tank Connection Space-separated from Tank. | - Outer tank: the function of the secondary barrier, creating a double containment system. |

The most commonly LNG fuel tank that applied in harbour tugs is the ISO tank because of this tank able to be moved by intermodal transportation, by road, rail and sea, low boil-off-rate (BOR), 0.15% up to 0. 30% per day, Holding time (55-81 days) and adjustable valve cabinets and instruments. However, this tank has disadvantages, one of which has a limited volume, so it must be reconsidered in using the tank in determining the type-C LNG tank to be used. Thus, it must take into account the demand for fuel
used and an estimate of the appropriate location. Therefore, the use of an LNG tank that is applied to the 2x2500 HP harbour tug has fuel requirements that exceed the capacity of the ISO LNG tank. It is also necessary to pay attention to the placement of the tank. So that for the selection of the LNG tank used on the 2x2500 HP harbour tug is a double-walled type C LNG tank.

2.4. Gas Valve Unit

Gas valve unit is one of supporting on the ship fuel system. This aim is to adjust the gas pressure that according to the load of the engine. Then it is supplied at all times with the gas pressure. The process is that the engine control system will operate GVU, which included a gas pressure control valve, a series of blocking and drain valves, manual shut-off valve, inerting connection system, filters, ventilation valve, pressure transmitters also temperature transmitters [15]. Generally, the GVU installation has two kinds of location, such as a separate room or a room with the main engine. GVU also divide into two zones, including the safe gas zone and the hazardous gas zone which ship bulkheads separate it. In this study, GVU will be designed based on the design requirement, which it can transfer the gas by engine supply gas requirement. The selection of components like the block valve, the filter also the indicators will determine by market exist.

2.5. Regasification Unit

The application of LNG fuel on ships is supported by several systems, including the regasification unit. This unit has a working principle of vaporizing LNG from the cryogenic tank, with the temperature is \(-162^\circ\text{C}\) into the gas by utilizing heat (heat input) [16]. The process of utilizing heat to reach LNG gas with the time and capacity required by the engine, it is vital to know the required and specified energy conversion calculations, which this heat indicator is highly dependent on geographical conditions such as the environment and weather.

| Methods | Advantage | Disadvantage | Working System | Selection |
|---------|-----------|--------------|----------------|-----------|
| ORV     | Cost operational is low | Seawater temperature use upper 5°C | ORV uses seawater to heat energy. Sodium hypochlorite aims to control algae growth. This method is only useful with seawater temperature is above 5°C. | Requires a large space for the regasification tool while the ship that designed only has a length of about 7.42 m |
| SCV     | Adaptable to the environment | The instrument limited | The water bath flow through tubes submersed and heated. | The heat produced has high efficiency and can utilize the exhaust gases from propulsion engines as burners |
| AAV     | Operational and capital cost is low | Produce gas emission | Air space is a source of heat energy. LNG fuel distributed through a series of pipes over the surface. | This method is climate-dependent, which ships sailing the weather always changes |
| IFV     | Thermal efficiency is high | Operational cost is high | a closed-loop and open-loop, or a combination of the two systems use in this method. | This method requires a large space and added to this method requires special handling in treating waste due to the fluid used |
| STV     | Space need quite small | Need additional heater | This method uses a tube that passes water for heat transfer process with a temperature of \(-160^\circ\text{C}\). | Able to be applied for ships because it does not require a large space if it still requires support pumps |

A large variable of regasification exist and have been developed by the time, including open-rack vaporizer (ORV), the submerged combustion vaporizer (SCV), the ambient air vaporizer (AAV), and intermediate fluid vaporizer (IFV) [17]. The variable of the regasification unit has advantages and
disadvantages. However, selecting the best system and able to apply into the ship is based on the availability of installations in a small engine room also small spaces on the main deck of harbour tug. In this study will briefly explain the comparison between each regasification which will later be applied to the 2x2500 HP harbour tug ship. In Table 3 below is a series of comparisons between the regasification unit methods conducted by [18].

The conclusion from this section as we can see from the table above that two methods can be installed on the ship, which is SCV.

2.6. Bunkering System
The use of LNG as ship fuel has applied. It is reinforced by the existence of regulations governing safety guidelines for gas fuel installations on ships. Although the application of LNG as not introduced by the IMO regulations, this is facilitated by the existence of an international code related to ships using low flashpoint fuel [19]. One of the things regulated in this regulation is the LNG bunkering system [20].

| Indicators | Truck-to-ship | Ship-to-ship | Port-to-ship |
|------------|---------------|--------------|--------------|
| Volume of delivery (m³) | 50 - 100 [19] | 100 - 6,500 [19] | 500 - 20,000 [19] |
| Flowrate of delivery (Q = m³/h) | 40 - 60 [19] | 500 - 1000 [19] | 1,000 - 2,000 [19] |
| The flexibility of operation, security also safety | - Limited movement [19] | - No interference to passenger/cargo [19] | - Good option for long-term bunkering [19] |
| | - Be as a start-up solution to probe the market [24] | - Flexible movement (moored, at anchor or the station) | - Pre-establish contract must exist to small storage |
| | - Has greater risk to the public because of proximity | - Remote locations reduce/eliminate potential exposure to vulnerable target [24] | - Limited movement |
| | - Less effect from the weather (except sea and wind) [25] | - Higher influence of weather also sea conditions [24] | - Good design for many customers [24] |
| Duration for tug (25,000 gal) (2) | 1.6 hr | 0.05 hr | 0.2 hr |
| Investment Cost | - Low capital investment due to portability [24] [26] | - Higher investment and operational cost than shore and truck-to-ship options [24] | - Higher investment and operational than truck-to-ship |

Research conducted by [22] state in the picture below that several methods can reach the delivery of LNG ship fuel, in which depending on the intended use of LNG. According to [18], the bunkering method in order to refuel ships (ship fuel) can be done using the truck-to-ship (TTS) method, the ship-to-ship (STS) method, and the port-to-ship (PTS) method or the portable tank transfer method. [20] state that the LNG bunkering method is determined by the amount of LNG sent to the ship. Each bunkering
method has its considerations and advantages. One of the considerations for determining the bunkering method is the length of time it takes to deliver the LNG from the port to the ship or vice versa [23]. In the table below, we will explain the complaints and weaknesses of each LNG bunkering method from various references which will be the basis for determining the bunkering method of the 2x2500 HP harbour tug ship.

The application of LNG bunkering using the truck-to-ship method is most used in ports where fuels used in the form of LNG. Due to in determining the method depends on the availability of places for bunkering [24]. Then, according to [25] the clustering of ships using the bunkering method depends on regulations, conditions and operational modes, which in the end is a tug that is included in the workboat type with a tank capacity above 100 m$^3$, namely by truck-to-ship (TTS) using a portable container. In result, the bunkering method that will be applied to the 2x2500 HP harbour tug is to use the truck-to-ship (TTS) bunkering method.

3. Result of Design Drawing System

In the methodology section, it has been explained regarding the determination of the operational mode, the type of LNG tank, the type of regasification unit and the method of the bunkering system. In this section, the fuel system design planning will be carried out. One of the main parameters in designing is the determination of endurance (operational endurance of the ship). That parameter aims to determine the fuel requirements of the fuel system used. The operational mode applying to 2x2500 HP harbour tug vessel refers to one of the vessels operating in a port in Indonesia with a high operational level.

| Operation Mode          | (time/ship) (%) | (time/day) (hr) | Power Load (%) | Power (kW) | Diesel Fuel Need (kg/day) | Gas Fuel Need (m$^3$/day) |
|-------------------------|-----------------|-----------------|----------------|------------|--------------------------|--------------------------|
| Start, stop, emergency  | 11              | 1.54            | 30             | 540        | 0.18                     | -                        |
| Full speed              | 9               | 1.26            | 84             | 1512       | -                        | 1.64                     |
| Tugging/towing          | 6               | 0.84            | 100            | 1800       | -                        | 0.74                     |
| Economic speed          | 22              | 3.08            | 53.30          | 959.4      | -                        | 1.34                     |
| Slow speed              | 47              | 6.58            | 55.30          | 995.4      | -                        | 3.28                     |
| Manouevering            | 5               | 0.70            | 71.33          | 1283.9     | -                        | 7.00                     |
|                         | Total           |                 |                |            | Total Needs (@day) 0.18  | 14.01                    |
|                         | Total           |                 |                |            | Total Needs (@5 days) 0.90 | 70.07                   |
|                         | Total           |                 |                |            | Total Needs (@7 days) 1.26 | 98.10                   |

Referring to the manufacturing engine that the gas consumption is 1,065 m$^3$/h; fuel density of 991 kg/m$^3$; SFOC 204.6 g/kWh and engine power of 1800 kW or 2500 HP. The reference ship operating hours are 14 hours per day. Table 5 above shows the fuel needs for both diesel fuel and LNG in @days, @5 days or @7 days, which will continue to the calculation and design of the LNG storage tank, regasification unit and gas valve unit and the determination of the bunkering system from harbour tug 2x2500 HP. Therefore, the selection of the fuel transfer system design determined using the built-up pressure.

3.1. LNG Tank Storage

In designing an LNG fuel tank, it is necessary to carry out several plans such as tank volume capacity, internal pressure, material planning and tank strength. Those plans are to get a design that complies to needs and tank requirements [26]. In operation, the tank capacity is not allowed in full conditions, and it is possible that changes in temperature, which affect the change in the form of LNG from liquid to
gas. The capacity required by the LNG type C (Pressure Vessels) tank is first assumed to be a cylinder with the diameter and length of the tank shown in the following equation

$$\text{Vol} = \frac{1}{4} \pi x D^2 x L$$  \hspace{1cm} (1)

Because the LNG tank capacity is not allowed to be filled due to changes in LNG temperature, which results in volume changes:

$$\text{Loading Limit} = \text{Filling Limit} \times \left(\frac{\rho_R}{\rho_L}\right)$$  \hspace{1cm} (2)

The loading limit is the maximum volume of liquid allowed relative to the tank volume. Whilst the filling limit is the maximum volume of a liquid relative to the total volume of the tank when the liquid fuel has reached the reference temperature. The density of reference temperature also divides by density of loading temperature. The volume of LNG tank required is

$$V = \text{Volume} \times \left(\frac{1}{\text{Loading Limit}}\right)$$  \hspace{1cm} (3)

The internal pressure includes design vapour pressure and liquid pressure. According to the IGC Code rules, design vapour pressure determine to the formula

$$P_0 = 0.2 \times 0.1 \times A \times C \times (\rho)^{1.5}$$  \hspace{1cm} (4)

$$A = 0.0185 \times \left(\frac{\sigma_m^2}{\sigma_A}\right)$$  \hspace{1cm} (5)

Where $P_0$ is the design steam pressure. $C$ is the tank’s feature sizes which is the maximum of the following values, $h$ (Height of the tank), $0.75b$ (0.75 times of the tank width), $0.45L$ (0.45 times of the tank length); $\rho$ is the density of the cargo at design temperature, Kg/m$^3$; $\sigma_m$ is the allowable stress of the material, The MPa $\sigma_A$ is the allowable dynamic stress of the material. The liquid pressure formula is below

$$P_{gd} = a\beta z\beta \frac{\rho}{1.02 \times 10^5}$$  \hspace{1cm} (6)

Where $a\beta$ is the relative acceleration due to gravity, resulting from gravitational and dynamical loads, in an arbitrary direction $\beta$. $Z\beta$ is the immense liquid height [m] above the point where the pressure is to be determined, measured from the tank shell in the $\beta$ direction.

| Table 6. Calculation Result of LNG Storage Tank |
|-----------------------------------------------|
| Indicators                  | Results | Units |
| LNG needs                   | 66.34   | m$^3$/weeks |
| Tank diameter (D)           | 4.07    | m       |
| Tank length (L)             | 6.00    | m       |
| Vapour pressure ($P_0$)     | 0.23    | MPa     |
| Tank density ($\rho$)       | 0.45    | ton/m$^3$ |
| Internal tank pressure (Peq) | 0.23    | MPa     |
| Liquid pressure ($P_{gd}$)  | 0.000076| MPa     |
| Tank thickness              | 1.10    | mm      |

The location or placement of the tank by the regulations set out in the IGF Code which aims to provide a safe location, space management and mechanical protection of fuel system equipment. The main requirements for placing the tank and for obtaining a suitable location as well as the fuel tank protect from external damage caused by a collision. The materials for fuel containment and piping systems must comply with the minimum regulations, for instance, the plates, parts and forgings for fuel tanks, secondary barriers and tanks for design temperatures must below minus 55°C and down to minus 165°C. The materials include 9% nickel steel, austenitic steel and aluminium alloy. The selection of the best material based on indicators such as allowable stress, minimal tensile strength and minimum yield
strength. From those materials, 9% nickel steel is the best quality of the three indicators above. So the harbour tug 2x2500 HP designs use 9% nickel steel.

**Figure 1.** Fuel system on harbour tug 2x2500 HP based on calculation and requirement

### 3.2. Regasification Unit

Based on the selection of the regasification unit above, it has been determined that the 2x2500 HP harbour tug uses the SCV type. In designing, it is necessary to carry out several calculations such as the calculation of fuel consumption need, and calculation of boil-off gas. Calculation of fuel consumption needs includes calculation of specific fuel consumption (SFGC), natural gas consumption, natural gas volume, mass and volume of natural gas per day.

\[
SFGC = SFOC \times LHV \quad (7)
\]

\[
NGC = SFGC \times P \times n \quad (8)
\]

In the LNG tank storage contains boil-off gas because the result of evaporation in the LNG tank storage, this evaporation can happen to cause the effect of ambient temperature, the value of boil of gas in the storage is about 0.1% – 0.15% of the volume LNG tank. This step calculates the boil-off gas in LNG storage for the purpose to determine the treatment with this BOG.

\[
Volume \ Tank = Volume \ LNG \times \left(\frac{1}{Loading \ Limit}\right) \quad (9)
\]

\[
Boil-Off \ Gas = Volume \ Tank \times Maximum \ Capacity \ of \ BOG \quad (10)
\]

### 3.3. Gas Valve Unit

GVU design planning refers to diesel engine manufacturers that apply a dual fuel system. This is because the characteristics of the GVU depend on the characteristics of the engine. In this study, the GVU design will be determined according to the engine required 2x2500 HP dual fuel diesel engine.
3.4. Bunkering System

In principle, the LNG transfer process between the three methods mentioned above is similar. However, technically the quantity to be transferred is different. Before the process of transferring LNG fuel from the port to the ship, it is necessary to monitor and control regularly both at the beginning, during bunkering and after bunkering. According to [27], several actions that must be considered in the bunkering process can be seen in the image below.

![Figure 2. The delivery method of bunkering LNG fuel system](image)

LNG bunkering begins with a process of pre-cooling, inerting, purging and stripping [28]. Pre-cooling process in term of the pipes does not experience cracks when LNG fuel flows. An inerting process that removes oxygen gas and vapour gas in the pipe to prevent hydrate formation. The purging process aims to remove the remaining inerting gas. Then the stripping process which aims to drain the remaining LNG in the pipe. This section describes the bunkering system design that has been determined in the previous section, namely using the truck-to-ship method. In designing the bunkering system, it is necessary to pay attention to in detail the rules that have been set by the IMO, and the classification aims to avoid fatal accidents and to simplify the bunkering process. [19] regulates the installation safety guidelines for ships that run on natural gas, for instance, determining the system, placement and specifications of the components.

4. Conclusion

The conclusion that can be drawn from this study is the planning of the 2x2500 HP harbor tug ship engine system design. Some of the components in the machining system are as follows:

a. The fuel system design is determined based on the operational mode. In this case, referring to the reference of a harbour tug operating in one of the Indonesian ports with a relatively high operating frequency, it is determined that it is 14 working hours for one day. In addition, the operational mode is determined based on the distribution of the load received by the engine which is divided into six types, namely start, stop and emergency, full speed, economical speed, slow speed and towing / tugging. So that the need for LNG and diesel fuel during @ day is 0.18 m³ and 14.01 m³, during @5 days is 0.90 m³ and 70.07 m³ and during @7 days is 1.26 m³ and 98.10 m³.

b. The choice of tank-type is based on operational mode and availability, so that the type of tank used is the type C LNG tank. The design of the LNG fuel storage tank is determined based on several factors including tank volume capacity, internal pressure, material and tank strength. The results of the LNG requirement are 66.34 m³/week, the tank LNG requirement is 78.05 m³, the tank diameter is 4.07 m, the tank length is 6 m, vapour pressure is 0.23 MPa, the liquid pressure is 0.000076 MPa, and tank thickness is 1.10 mm.

c. Selection of the type of regasification based on the method and availability for installation on ships is the submerged combustion vaporizer (SCV) method. This is because besides being adaptable to the environment, it also has high efficiency and can take advantage of the heat from the engine exhaust gas. Then in the regasification unit design based on the characteristics of the diesel engine, including the specific gas consumption, natural gas consumption and the boil-off capacity of the LNG evaporating in the LNG tank.
d. The selection and design of the gas valve unit is based on the characteristics of the engine used. Therefore, designing a GVU that needs to be considered is determining the method whether the GVU is located outside or is a zone with the ship's main engine.

e. The selection of the bunkering system method using a qualitative assessment has been carried out. Based on availability and flexibility in operations, the truck to ship method is the method used in the bunkering system on 2x2500 HP harbour tug ships.

5. References

[1] Biro Perencanaan dan Informasi 2020 Kebijakan Green Port Untuk Mendukung Indonesia sebagai Poros Maritim Dunia Kemitraan dan investasi maritim.go.id, https://maritim.go.id/kebijakan-green-port-untuk-mendukung-indonesia-sebagai-poros-maritim-dunia/.

[2] N. Ahmadi, T. Kusumastanto, and E. I. Siahaan 2018 Strategi Pengembangan Pelabuhan Berwawasan Lingkungan (Greenport) Studi Kasus: Pelabuhan Cigading-Indonesia War. Penelit. Perhub., vol. 28, no. 1, p. 9, doi: 10.25104/warlit.v28i1.697.

[3] P. K. Balakrishnan and S. Sasi 2016 Technological and Economic Advancement of Tug Boats IOSR J. Mech. Civ. Eng., vol. 87, no. January, pp. 2278–1684.

[4] G. de Melo Rodriguez and J. C. Murcia 2013 Analysis and Measurement of NOx Emissions in Port Auxiliary Vessels TransNav, Int. J. Mar. Navig. Saf. Sea Transp., vol. 7, no. 3, pp. 421–429, doi: 10.12716/1001.07.03.15.

[5] B. Thomson 2020 Tug Profile Provides Challenge for Clean and Efficient Operations The Motorship. https://www.greenport.com/news101/Products-and-Services/tug-profile-provides-challenge-for-clean-and-efficient-operations.

[6] DNV-GL 2014 LNG as ship fuel: The future - today

[7] K. Watanabe 2011 High Operation Capable Marine Dual Fuel Engine Journal of the JIME

[8] H. Grim melius, P. de Vos, M. Krijgsman, and E. van Deursen 2011 Control of Hybrid Ship Drive Systems COMPIT (10th Int. Conf. Comput. Appl. Inf. Technol. Marit. Ind., no. March, p. 15.

[9] A. Ghazi 2015 Dual-Fuel Diesel Engines. New York: 2015 by Taylor & Francis Group, LLC

[10] J. B. Heywood 1988 Internal Combustion Engine Fundamentals vol. 21

[11] S. Kumar et al. 2011 LNG: An eco-friendly cryogenic fuel for sustainable development Appl. Energy, vol. 88, no. 12, pp. 4264–4273, doi: 10.1016/j.apenergy.2011.06.035.

[12] J. Li, B. Wu, and G. Mao 2015 Research on the performance and emission characteristics of the LNG-diesel marine engine J. Nat. Gas Sci. Eng., vol. 27, pp. 945–954, doi: 10.1016/j.jngse.2015.09.036.

[13] P. Ni, X. Wang, and H. Li 2020 A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines Fuel, vol. 279, no. June, doi: 10.1016/j.fuel.2020.118477.

[14] M. Chorowski, P. Duda, J. Polinski, and J. Skrzypacz 2015 LNG systems for natural gas propelled ships IOP Conf. Ser. Mater. Sci. Eng., vol. 101, no. 1, doi: 10.1088/1757-899X/101/1/012089.

[15] A. Armón Feasibility and Technological development study on an LNG-powered rescue boat

[16] R. Agarwal, T. J. Rainey, S. M. Ashrafur Rahman, T. Steinberg, R. K. Perrons, and R. J. Brown 2017 LNG regasification terminals: The role of geography and meteorology on technology choices Energies, vol. 10, no. 12, doi: 10.3390/en10122152.

[17] S. Xu, X. Chen, and Z. Fan 2016 Thermal design of intermediate fluid vaporizer for subcritical liquefied natural gas J. Nat. Gas Sci. Eng., vol. 32, no. April 2016, pp. 10–19, doi: 10.1016/j.jngse.2016.04.031.

[18] G. Lloyd 2013 European Maritime Safety Agency (EMSA) - Study on Standards and Rules for bunkering of gas-fuelled Ships p. 108, [Online]. Available: http://www.lngbunkering.org/sites/default/files/2012%2C GL%2C Final report of European Maritime Safety Agency (EMSA) Study on Standards and Rules for Bunkering of Gas-Fuelled Ships.pdf%2Afiles/997/Germanischer Lloyd - European Maritime Safety Agenc.

[19] International Maritime Organization (IMO), MSC.285 (86) 2009 Interim Guidelines on Safety NG Installation in Ships
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