Technical Analysis of Diesel Engine Convert to Dual Fuel Engine for the Ship

Semin¹, B Cahyono¹ and I R Kusuma¹

¹Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia

Email : semin@its.ac.id

Abstract. Fossil fuel is the high-cost price. This trend of price is increasing and not stable. For the future is need alternative low cost and stable price fuel. Natural gas has low cost and stable price for alternative fuel. The objective of this paper is to analyze the effect of diesel engine converted to dual fuel engines using. The method of this paper is a mixture of HSD with CNG conducted on the ship diesel engine. The conversion is determining additional components required. Then, the reduction of the cargo for two cars for cylinder placement used. After the engine has been changed to dual fuel, the performance investigated. The performance investigation is based on the variation of HSD and CNG fuel composition in the engine. The result has shown that the best performance is when the 30: 70 of CNG: HSD mixture composition.

1. Introduction

Natural gas fuel has high methane content 90% and octane value (120-130) and has environmentally friendly combustion characteristics, therefore engine efficiency is higher and lower emissions. Usually, the method used for storing natural gas is compressed to 3600 psi (pounds per square inch), which is called Compressed Natural Gas (CNG). For that, the CNG tube has a thickness and greater strength compared to gasoline and diesel fuel storage [1-4]. As global energy demand rises, natural gas plays an important strategic role in energy supply. Natural gas is the cleanest fossil fuel that has been investigated extensively for use in spark-ignition (SI) and compression-ignition (CI) engines [5-11]. Efficient use of energy and other alternative energy sources, as necessary to minimize the use of fuel oil, so as to save petroleum reserve.

Figure 1 has been shown that in the period of 1980 - 2012. In the 80s to 90s years, oil production is still very meet for consumer needs. However, since the 1990s oil demand has been increasing rapidly until the 2000s oil production is lower than the necessary demand, forcing the government to import oil from abroad to meet those needs. One effort that can be solved to overcome this problem is to switch to the use of other alternative fuels, to be able to function to replace the energy source of oil that has been reduced. In this case, it can be replaced by utilizing natural gas energy sources, which are some of the more favourable reasons than fuel oil, which is cheaper prices of fuel oil, and higher octane levels and cleaner and environmentally sound exhaust emissions if In comparison with fuel oil. But the need for modifications to the diesel engine before it can use an alternative fuel gas [12-17].
The ship’s fuel system is a system used to supply the fuel required by the main engine. From the fuel storage tanks will be sucked by the feed pump to flow through the fuel pipe to the fuel filter and heated using a heater before injection to the engine to meet the engine's entry temperature of about 45°C. Then the fuel is flowed through the injection pipe to be injected into the combustion chamber by the injector. Dual fuel engine is an engine that has two different fuel supply systems and operates with two types of fuel simultaneously. There are two types of dual fuel systems based on the characteristics of the fuel that is liquid and gaseous. In this analysis, the dual fuel system used is High-Speed Diesel (HSD) and CNG fuel. CNG as a fuel has characters of high Joule values, low applied technical threshold, and almost zero air pollution emission [17-19].

Hidayat [3] has been investigated the experimental performance of dual fuel engine modified from the diesel engine, using diesel engine Yanmar TF-85 H direct injection 1-cylinder. Analyze the performance of diesel fuel oil and diesel fuel and to determine the effect of gas fuel consumption on diesel fuel consumption in diesel motors from experimental results. With variable variation is load and rpm, with the variation of fuel is 100% diesel, 10% CNG and 20% CNG. The results from the experiments showed power and torque using 20% CNG decreased by 0.92% and 0.70% respectively, while fuel consumption decreased by 0.97%. So it can be concluded that the use of CNG is more efficient than using only fuel oil.

The objective of this paper is to discuss the effect of diesel fuel convert to dual fuel which is done with the determination of additional components required fuel supply.

| Tittle                  | Information                          |
|-------------------------|--------------------------------------|
| Ship Name’s             | MV. Legundi                          |
| Type                    | Passenger Ship                       |
| Voyage                  | Port of Merak – Port of Bakauheni    |
| LPP                     | 99.2 m                               |
| Breadth (B)             | 19.6 m                               |
| Height (H)              | 5.6 m                                |
| Draught (T)             | 4.1 m                                |
| Speed                   | 16 knots                             |
| Gross Tonnage           | 5000 GRT                             |

2. Methods
This research was conducted in Lab. of Ship Engine, Dept. of Marine Engineering (DMarE), Institut Teknologi Sepuluh Nopember (ITS), Surabaya Indonesia and on MV. Legundi which is a ferry ship.
with the route is from port of Merak to port of Bakauheni Indonesia. Modify the fuel system from single fuel to dual fuel. By specifying the additional components needed in the modification to HSD-CNG fuel engines as well as performance analysis of the engine, including power, torque, brake mean effective power (BMEP), specification fuel oil consumption (SFOC), low heating value (LHV), compression ratio, eff. thermal. But in this paper, it will only discuss related conversion to dual fuel from a technical point of view that includes dual fuel system planning that will be used. Because diesel is converted to diesel fuel with natural gas generally requires additional components as well as some mechanical changes to the engine [20-22].

Collection data of the ship based on data needed in research. In this case, there is some data needed as a supporter, including as presented in Table 1 and Table 2.

Table 2. Specification of Engine [2]

| Title                                      | Information                                      |
|--------------------------------------------|--------------------------------------------------|
| Manufacturer / Model                       | YANMAR 6N330W, 4-Stroke, Diesel                  |
| Continuous Rated Power                     | 2574 kW / 3500 HP                                |
| Rated Engine Speed                         | 620 rpm                                          |
| No. of Cylinder                            | In-line 6                                        |
| Cylinder Bore                              | 330 mm                                           |
| SFOC                                       | 191±5% gr/kW.h                                   |
| Piston Stroke                              | 440 mm                                           |
| Piston Speed                               | 9.09 m/s                                         |
| Mean Effective Pressure                    | 1.89 – 2.21 Mpa                                  |

In addition to Indonesia's petroleum has large natural gas reserves of 170 TSCF and annual production of 2.87 TSCF, with the composition Indonesia has a reserve to production (R/P) of 59 years. Natural gas also has a stable price because it is far from political content, unlike petroleum30. Below are the characteristics data of HSD and CNG fuels to be used, shown in Table 2, 3 and 4.

Table 3. Properties of HSD [3]

| Properties                        | Units | Value |
|-----------------------------------|-------|-------|
| Density on 15°C                   | Kg/m³ | 880   |
| Cetane Number                     | -     | ± 50  |
| Lower Heating Value (LHV)         | MJ/kg | ± 44  |
| Sulphur Content                   | % (m/m)| Max. 0.4 |
| Pour Point, °C                    | Winter| Max. 0 |
| Flash Point, °C                   | Winter| Max. 6 |
| Sediment Content                  | % m/m | Max. 0.1 |
| Water Content                      | % (v/v)| Max. 0.3 |
| Viscosity on 40°C                 | Mmmm²/s| 6-11 |

In determining the amount of fuel consumption of gas used then determined based on the calculation of LHV. LHV itself is the value of heat that states the amount of heat or calories produced in the combustion process at a certain amount of fuel with air [23].

The calculation uses the following equation (1):

\[ LHV_{\text{engine}} = LHV_{\text{HSD}} \cdot FOC \]  

where:

- \( LHV_{\text{engine}} \) = Low Heating Value of Diesel Engine (MJ)
- \( LHV_{\text{HSD}} \) = Low Heating Value of HSD (MJ/kg)
- \( FOC \) = Fuel Oil Consumption (kg/day)
### Table 4. Properties of CNG [5]

| Properties                                      | Unit   | Value |
|-------------------------------------------------|--------|-------|
| Density                                         | Kg/m³  | 0.72  |
| Flammability Limits in Air                      | Volume % | 4.3 – 15 |
| Flammability Limits                             | Ø      | 0.4 – 1.6 |
| Auto ignition Temperature in Air                | °C     | 723   |
| Minimum Ignition Energy                         | mJ     | 0.28  |
| Flame Velocity                                  | m/s    | 0.38  |
| Adiabatic Flame Temperature                     | K      | 2214  |
| Quenching Distance                              | Mm     | 2.1   |
| Stoichiometric Fuel/Air Mass Ratio              | -      | 0.058 |
| Stoichiometric Volume Fraction                  | %      | 9.48  |
| Lower Heating Value (LHV)                       | MJ/Kg  | 45.8  |
| Heat of Combustion                              | MJ/Kg air | 2.9 |

Then determine the LHV value using engine dual fuel by estimating the percentage of HSD and CNG fuel mixtures to be used in daily operating times, calculated each using equation (2):

\[ \text{LHV} = \text{LHV}_{\text{Engine}} \cdot \text{percentage of fuel} \] (2)

where :

\[ \text{LHV} = \text{LHV HSD or CNG (MJ.Kg)} \]

Therefore, it can be known the mass of HSD and CNG fuel used from the equation (3):

\[ \text{Mass} = \text{LHV}_{\text{Engine}} : \text{LHV} \] (3)

where :

\[ \text{Mass} = \text{Mass HSD or CNG (Kg)} \]

As for to express the consumption of CNG unit Kilogram (Kg) using equation (4) and for HSD fuel consumption using equation (5):

\[ \text{CNG}_{\text{Csump}} = \text{Mass}_{\text{CNG}} \cdot 0.0462 \text{ mmBtu} \] (4)

\[ \text{HSD}_{\text{Csump}} = \text{LHV}_{\text{HSD engine}} (\text{MJ}) : \text{LHV}_{\text{HSD}} (\text{MJ/Kg}) \] (5)

\[ \text{CNG}_{\text{Csump}} = \text{CNG consumption (mmBtu)} \]

\[ \text{HSD}_{\text{Csump}} = \text{HSD consumption (Kg)} \]

### 3. Result and discussion

The engine used is a conventional diesel engine, but modifications are made with the addition of components to be operated in dual fuel mode. In dual fuel mode, the engine will operate using HSD-CNG fuel, the diesel will be injected first to start the combustion because the gas has a higher combustion temperature than the diesel fuel. So, it has been more efficient if using diesel for the first explosion. The combustion will increase the pressure and temperature in the combustion chamber so that the fuel gas that has been mixed can be burned.

In modifying the fuel system using combination fuels between HSD and CNG, equipment is required to support modifications to supply the CNG fuel required by the engine. For that need to do the determination of equipment to be added as a supporter of the dual fuel system in MV. Legundi is shown in Figure 2 and Table 5.
According to Semin et al [11] the injection method of CNG is an effective method to reduce emissions. The gas injectors are placed at the intake manifold and close to the inlet valve. All of these components are connected to the dual fuel ECU.

The CNG tube will be used for storage of CNG fuel needs on board as shown in Figure 3, Figure 5 – Figure 7. The gas storage tank or cylinder data is shown in Table 6. Based on the data of fuel consumption within a certain period obtained from the MV. Legundi Indonesia Ferry. Then the data can be processed to determine the value of fuel consumption required by the ship when using a mixture of HSD-CNG fuel and the determination of the number of CNG tubes required. At atmospheric pressure and temperature, natural gas exists as a gas and has low density. Since the volumetric energy density (joules/m3) is so low, natural gas is often stored in a compressed state CNG at high pressure stored in pressure vessels [21].

**Figure 2.** Installing modifications to dual fuel

**Table 5.** Description of component

| No. | Description                           | No. | Description                |
|-----|---------------------------------------|-----|----------------------------|
| 1   | Switch Mode Diesel – Dual Fuel        | 8   | CNG Injector               |
| 2   | Engine Control Unit (E.C.U)           | 9   | Toothed Wheel              |
| 3   | Safety Valve                          | 10  | Reduction sensor           |
| 4   | CNG Cylinder                          | 11  | Engine                     |
| 5   | Gas Level Sensor                      | 12  | Diesel Pump                |
| 6   | Reducer Pressure                      | 13  | Electro Mechanical Actuator (EMA) |
| 7   | Pressure Sensor                       | 14  | Diesel Injector            |
Figure 3. CNG Cylinder type 3 [21]

Table 6. Specification of CNG storage tank [21]

| Title                     | Information            |
|---------------------------|------------------------|
| Type                      | CNG Cylinder Type 3    |
| Standard of Manufacture   | ISO 11439-2000         |
| Pressure of Working (bar/psi) | 250/3600           |
| Weight in Empty           | 64 Kg                  |
| Capacity of Water         | 150 L                  |
| Diameter                  | 396 mm                 |
| Height                    | 1633 mm                |

Figure 3 is the type of tube used in this planning, CNG cylinder 3 has an aluminium material wrapped in a composite (carbon fibre), but the difference with type 2 is that all of these 3 type liner surfaces are enclosed. This type has a lighter weight than the two previous types and is good anti-corrosion [21].

Table 7. Dual fuel percentage mixture

| Percentage of Fuel | Unit   | 30%    | 40%    | 50%    | 60%    | 70%    |
|--------------------|--------|--------|--------|--------|--------|--------|
| FOC/trip           | Kg/trip| 452.9  | 452.9  | 452.9  | 452.9  | 452.9  |
| LHV\_CNG           | MJ/kg  | 45.8   | 45.8   | 45.8   | 45.8   | 45.8   |
| LHV\_HSD           | MJ/kg  | 44     | 44     | 44     | 44     | 44     |
| LHV\_engine        | MJ/trip| 19927.9| 19927.9| 19927.9| 19927.9| 19927.9|
| LHV\_DDF-CNG       | MJ/trip| 5978.37| 7971.16| 9963.95| 11956.7| 13949.5|
| LHV\_DDF-HSD       | MJ/trip| 5978.37| 7971.16| 9963.95| 11956.7| 13949.5|
| CNG\_CSump          | Kg     | 130.53 | 174.04 | 217.55 | 261.06 | 304.57 |
| HSD\_CSump          | Kg     | 135.87 | 181.16 | 226.45 | 271.74 | 317.03 |

The values obtained in Table 7 and Figure 4 are shows the fuel consumption of each variation of the HSD-CNG fuel mixture. The difference shown from the value of the fuel mixture in Kg units is changing, but using the CNG mixture there is a savings rather than using only fuel oil.
The values obtained in Table 7 and Figure 4 are shows the fuel consumption of each variation of the HSD-CNG fuel mixture. The difference shown from the value of the fuel mixture in Kg units is changing, but using the CNG mixture there is saving rather than using only fuel oil. For consideration of the composition of CNG and diesel fuel mixtures used are based on the most efficient amount of these variations. And from the five composition variations which have been calculated the lowest amount of mixture is 70: 30% CNG-HSD so in the determination of CNG storage tank refers to the value. By using the mix ratio of HSD-CNG of 30:70. In one trip MV. Legundi requires about 9 CNG cylinder tubes, so in a day that has a range of 4 times trip will require 36 CNG cylinder tube type 3 ISO 11439: 2000 every day.

![Figure 4. Variation of CNG-HSD consumption](image)

| CNG Consumption | 130.532 | 174.043 | 217.553 | 261.064 | 304.575 |
|-----------------|---------|---------|---------|---------|---------|
| HSD Consumption | 317.03  | 271.74  | 226.45  | 181.16  | 135.87  |

![Figure 5. Layout CNG fuel cylinder](image)
Figure 6 shows the original car deck arrangement. Figure 7 shows the location of CNG tube placement located in an open field that is the 2nd level vehicle deck. Related to gas pipeline rules that will be planned in a ship, refer to BKI (Indonesian Bureau of Classification) Vol. I – Guidelines for The Use of Gas as Fuel for Ship [24]:

a) Fuel pipes shall not be located less than 800 mm from the ship's side.
b) Fuel piping shall not be led directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention.
c) Fuel pipes led through Ro-Ro spaces, special category spaces and on open decks shall be protected against mechanical damage.
d) Gas fuel piping in ESD protected machinery spaces shall be located as far as practicable from them electrical installations and tanks containing flammable liquids.

e) Gas fuel piping in ESD protected machinery spaces shall be protected against mechanical damage.

4. Conclusion
The use of a dual fuel HSD-CNG mixture has been affected the amount of fuel required as well as the supporting components of the CNG supply from the cylinder to the engine. In addition, there was a reduction of the cargo of two cars as the weight and cylinder placement used. And the engine best performance in this research is when the 30:70 dual fuel HSD-CNG mixture.

References
[1] Semin, Bakar R A, Ismail A R 2009 Compressed natural gas as an alternative fuel for internal combustion engines a technical review International Review of Mechanical Engineering 3 (2) pp 188-195
[2] Fitriana. A 2013 Technical and Economic Review of Dual Fuel Installation on the Tug Boat of PT. Pelabuhan Indonesia II Jurnal Teknik 2 (2)
[3] Hidayat A W 2013 Experimental Study of Dual Fuel Engine Working Modification of Diesel Engine Jurnal Teknik 2 (1)
[4] Bakar R A, Semin, Ismail A R, Ali I 2008 Computational simulation of fuel nozzle multi holes geometries effect on direct injection diesel engine performance using GT-POWER American Journal of Applied Sciences 5 (2) pp 110-116
[5] Semin, Ismail A R, Bakar R A 2008 Comparative performance of direct injection diesel engines fueled using compressed natural gas and diesel fuel based on GT-POWER simulation American Journal of Applied Sciences 5 (5) pp 540-547
[6] Octaviani N S, Semin, Zaman M B 2018 The implementation of CNG as an alternative fuel on marine diesel engine International Journal of Mechanical Engineering and Technology 9 (13) pp 24-33
[7] Semin, Bakar R A 2014 Computational modelling the effect of new injector nozzle multi diameter holes on fuel-air mixing homogeneous of CNG engine International Journal of Applied Engineering Research 9 (21) pp 9983-9988
[8] Semin, Bakar R A 2013 Simulation and experimental method for the investigation of compressed natural gas engine performance International Review of Mechanical Engineering 7 (7) pp 1427-1438
[9] Semin 2012 Injector nozzle spray on compressed natural gas engines a technical review International Review of Mechanical Engineering 6 (5) pp 1035-1043
[10] Semin, Ismail A R, Bakar R A 2009 Investigation of torque performance effect on the development of sequential injection CNG engine Journal of Applied Sciences 9 (13) pp 2416-2423
[11] Semin, Ismail A R, Bakar R A, Ali I 2008 Heat transfer investigation of intake port engine based on steady-state and transient simulation American Journal of Applied Sciences 5 (11) pp 1572-1579
[12] Semin, Ismail A R, Bakar R A 2009 Gas fuel spray simulation of port injection compressed natural gas engine using injector nozzle multi holes European Journal of Scientific Research 29 (2) pp 188-193
[13] Semin, Idris A, Bakar R A, Ismail A R 2009 Engine cylinder fluid characteristics of diesel engine converted to CNG engine European Journal of Scientific Research 26 (3) pp 443-452
[14] Semin, Ismail A R, Bakar R A 2008 Investigation of CNG engine intake port gas flow temperature based on steady-state and transient simulation European Journal of Scientific Research 22 (3) pp 361-372
[15] Semin 2015 Investigation the effect of injector nozzle multi holes geometry on fuel spray distribution flow of CNG engine based on computational modelling International Journal of Applied Engineering Research 10 (15) pp 36087-36095
[11] Semin, Gusti A P, Octaviani N S, Zaman M B 2016 Effect of new injector on the torque performance characteristics of gas engine International Journal of Applied Engineering Research 11 (11), pp. 7467-7471
[12] Octaviani N S and Semin 2020 Effect of fin addition on inlet valve on air-gas intake flow of dual fuel engine based on computational modelling International Review of Mechanical Engineering 14 (1) pp 18-24
[13] Semin, Zaman M B, Santoso A 2019 Effect of Compression Ratio Improvement on the Performance of Dual Fuel Engine International Review of Mechanical Engineering 13 (3) pp 142-147
[14] Semin, Felayati F M, Cahyono B, Zaman M B 2019 Improvement approaches for the combustion process of recent diesel natural gas dual fuel engines-A technical review International Review of Mechanical Engineering 13 (3) pp 198-202
[15] Wei L and Geng P 2016 A review on Natural Gas/Diesel Dual Fuel Combustion, Emissions and Performance Fuel Processing Technology 142 pp 264–278
[16] Wibawa A, Alam S R 2013 Utilization of Alternative Energy of Compressed Natural Gas as Fuel of Traditional Fisherman's Fishing Machine. Journal of Kapal 9 (1)
[17] Cho H M, He Bang-Quan 2007 Spark ignition natural gas engines - A review Energy Conversion and Management 48 pp 608–618
[18] Ehsan M B 2009 Dual fuel performance of small diesel for application with less frequent load International Journal of Mechanical and Mechatronics Engineering 9 (10) pp 30-39
[19] Hasannuddin A K 2016 Performance, emissions and lubricant oil analysis of diesel engine running on emulsion fuel. Energy Conversion and Management 117 pp 548–557
[20] Xu B Y, Liang F Y, Cai S L And Qi Y L 2005 Numerical Analysis of Fuel Injection In Intake Manifold And Intake Process of A MPI Natural Gas Engine. International Journal of Automotive Technology 6 (6) pp 579–584
[21] Yang X, Hu X, Yang X, Hu K 2010 Technical Practice of Compressed Natural Gas Fueled Ship Journal of Ship Production and Design 26 (3) pp 211-218
[22] Yerrennagoudaru H and Prasad D S 2015 Generation of Air Swirl Through Inlet Poppet Valve Modification and to Enhance Performance on Diesel Engine. IOSR Journal of Mechanical and Civil Engineering 12 (6) pp 2278–1684
[23] Heywood J B 1998 Internal Combustion Engine Fundamentals McGraw-Hill Singapore.
[24] BKI 2015 Guidelines for the Use of Gas as Fuel for Ship BKI Vol I

Acknowledgements
Authors very express the acknowledge to Menristek/BRIN RI, Research Institute of ITS for the support of the PTUPT Grant No. 1335/PKS/ITS/2020 to funding of this research.and Nur Aulia Rosyida for the support of this research.