DESIGN OF DUAL FUEL SYSTEM FOR MAIN ENGINE ON CNG CARRIER VESSEL

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ABSTRACT

Increased energy consumption in Indonesia has increased significantly every year. This includes fuel oil consumption on the ship. In this research will focus on designing a dual fuel system for the main engine CNG Carrier vessel where the fuel used is a combination of fuel oil and CNG. And the other focus, CNG is taken from the cargo of the ship. So that the gas cargoes will be used to fuel the ship's main engine, and then the vessel operating costs can be reduced. The approach used in this research is the method of analysis, calculation and design. In this research is expected to know the optimal point that can be a reference of fuel oil usage and gas fuel on the ship. So that the vessel operating costs can be reduced because using dual fuel system for main engine propulsion. And for diesel engine performance and diesel engine conversion shows that from the analysis shows that when using dual fuel, the engine decreased performance. By using the mix ratio of HSD-CNG of 40:60, 30:70, 20:80, and 10:90, in one trip CNG carrier requires about 18-27 CNG cylinder tubes.

Keywords: CNG carrier, dual fuel, main engine, modification, optimization.

INTRODUCTION

Indonesia is the largest archipelago where it consists more than 17,000 islands scattered in an area of 1,904,569 km^2. The archipelago conditions complicate the development of many aspects and creates a condition where several islands in Indonesia are not evenly.
Because of geographical condition, it is necessary that reliable mode of transportation as a maritime nation consisting of many islands. Therefore ship technology is the absolute transportation must be mastered. Because the ship is a key in economic and key to the mobility of cargo and people.
Fossil fuel are highly consumed to produce energy but emission substance like CO2, NOx and SOx discharged by fossil fuel are produced in significant amount. Associated with the regulation a ship built after 1 January 2016 must comply with pollution regulation, therefore to meet the new standard, CNG fuel is considered due to its level of cleanliness compared to other fossil fuel.
In addition, the use of CNG fuel can reducing the operational cost of the ship, because gas prices are cheaper than fuel oil prices with relatively similar heating value. Therefore, the application of CNG use on ships should be developed. In this research will be designed dual fuel system on CNG carrier vessel where the ship is carrying CNG then take some of its cargo for the ship's main engine.

Diesel dual fuel (DDF) 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, 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.

METHOD

This research was applied to CNG Carrier vessel with the route is from port of Gresik to port of Lombok, Indonesia. Modify the fuel system on diesel engine 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, and thermal efficiency. 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.

Collection of data based on data needed in research. In this case there is some data needed as a supporter, including as follows.

Table 1. Ship principal dimension.

Ship Dimension	
Length over all (Loa)	110,92 m
Length between perpendicular (Lpp)	104,12 m
Breadth (B)	17,60 m
High (H)	9 m
Draught (D) design	5,2 m
Speed (Vs)	15 knot

Below is the data about main engine used on CNG carrier vessel. Main engines are used instead of dual fuel diesel engine, therefore it needs to be modified to be a dual fuel diesel engine. So there is an additional component that needs to be installed.

Table 2. Main engine data.

Engine	Wartsila 9L34; 4-stroke; non-reversible
Power	4050 kW @750 RPM
Cylinder bore	340 mm
Stroke	400 mm
Piston displacement	36.3 l/cyl
Number of valves	2 inlet valves and 2 exhaust valves
Cylinder configuration	6 and 9 in-line; 12 and 16 in V-form
Direction of rotation	Clockwise, counterclockwise on request
Speed	720, 750 rpm
Mean piston speed	9.6, 10.0 m/s

CNG carrier vessel is a CNG gas transport vessel sent from Gresik to Lombok Island, where CNG is used to supply power plant that is there. Below is the data on the CNG tube that the ship was carrying.

Table 3. Cargo data (CNG).

CNG tubes	
Diameter	0.6 m
Length	12 m
Pressure	200 bar
Quantity	832
Total capacity	26 mmscf
Capacity per tube	0.03125 mmscf
Capacity per tube	885 m^3 gas
Weight of CNG	637.2 kg

Main engine on board initially use high speed diesel fuel (HSD) to supply. The following is technical data about the properties of HSD used on ships.

Table 4. Properties of HSD

Properties	Units	Value
Density on 15ºC	Kg/m^3	880
Cetane Number	-	± 50
Lower Heating Value (LHV)	MJ/kg	± 44
Sulphur Content	% (m/m)	Max. 0,4
Pour Point, ºC	Winter	Max. 0
	Summer	Max. 6
Flash Point	ºC	Min. 60
Sediment Content	% m/m	Max. 0,1
Water Content	% (v/v)	Max. 0,3
Viscosity on 40ºC	Mm^2/s	6-11

The following is technical data about CNG gas transported by vessel, besides this CNG will also be used to supply ship main engine, so the vessel becomes dual fuel diesel engine.

Table 5. Properties of CNG

Properties	Unit	Value
Density	Kg/m^3	0,72
Flammability Limits in Air	Volume %	4,3 – 15
Flammability Limits	Ø	0,4 – 1,6
Auto ignition Temperature in Air	ºC	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

The following is a general arrangement of a CNG carrier vessel that will be modified into a vessel using dual fuel. This ship carrying as many as 832 CNG tubes.

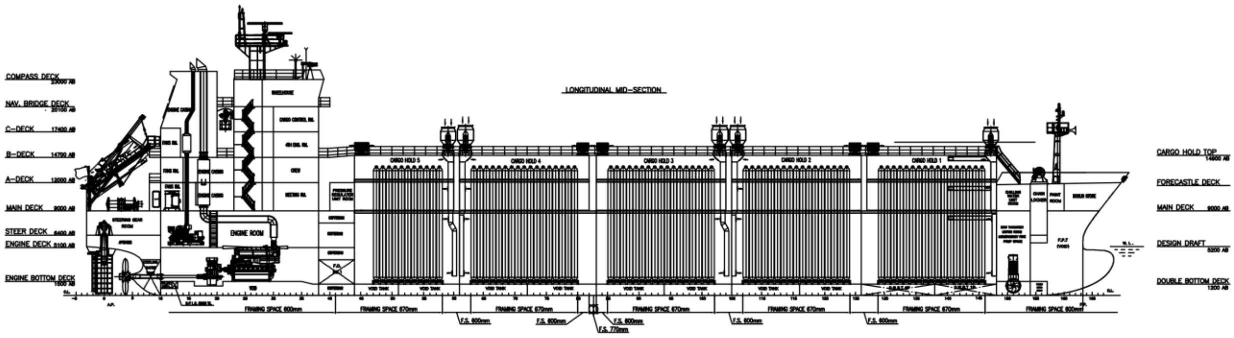

Figure 1. General arrangement of CNG carrier vessel

Determination of Modification Components

1. Determine fuel consumption requirements.
2. Determine the HSD-CNG composition to be used.
3. Determine Low Heating Value.
4. Determine the number of HSD-CNG to be determined.
5. Determine the other supporting components required for modification and specification.

In determining the amount of fuel consumption of gas used then determined based on the calculation of LHV. LHV it self 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.
The calculation uses the following equation:

LHV_{engine} = LHV_{HSD} x FOC (1)

where:

LHV_{engine} : LHV Diesel Engine (MJ)
LHV_{HSD} : LHV HSD (MJ/kg)
FOC : Fuel Oil Consumption (kg/day)

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 with equation:

LHV = LHV_{engine} x percentage of fuel (2)

where:

LHV : LHV HSD or CNG (MJ/Kg)

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

Mass = LHVengine / LHV (3)

where:

Mass : Mass of 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:

$CNG_{consumpt}$ = Mass of CNG x 0.0462 mmBtu (4)
$HSD_{consumpt}$ = $LHV_{HSDengine}$ (MJ) / LHV_{HSD} (MJ/Kg) (5)

where:

$CNG_{consumpt}$: CNG consumption (mmBtu)
$HSD_{consumpt}$: HSD consumption (Kg)

RESULTS AND DISCUSSION

Conversion to Diesel Engine Dual Fuel

CNG carrier vessel using 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 so it will be 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 by 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 dual fuel system in CNG carrier vessel.

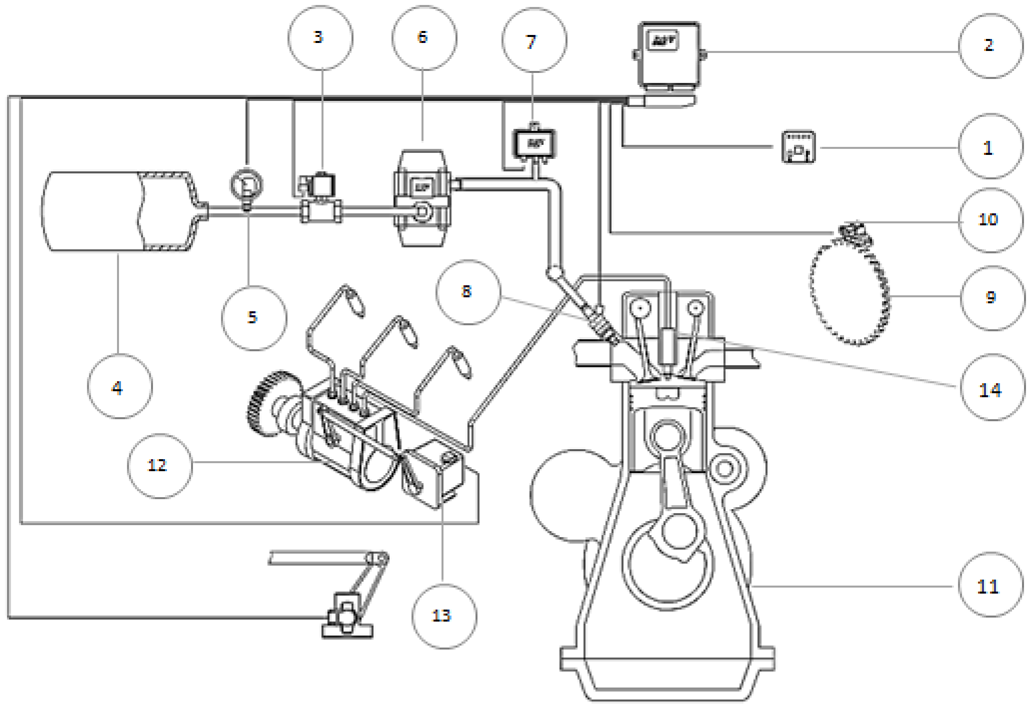

Figure 2. Main engine modifications to Dual Fuel

Figure 2 is a modification made to conventional diesel engines on a CNG carrier vessel to operate into dual fuel. So that required additional components for the main engine can operate into dual fuel. Figure 2 also shows the schematic and flow of HSD and CNG to the combustion chamber. Here is the explanation.

1. Switch Mode Diesel – Dual Fuel
2. Engine Control Unit (E.C.U)
3. Safety Valve
4. CNG Cylinder
5. Gas Level Sensor
6. Reducer Pressure
7. Pressure Sensor
8. CNG Injector
9. Toothed Wheel

10. Reduction sensor
11. Engine
12. Engine driven pump
13. Electro Mechanical Actuator (EMA)
14. Diesel Injector

Double fuel engine system can not work with dual fuel system only, but also available single fuel system that is using diesel fuel. If the condition of the fuel gas system occurs suddenly discharged or gas runs out, the gas fuel valve will be closed immediately and the operation using only diesel fuel can be run directly with the same parameters as before the conversion. Thus, the replacement of the fuel system from dual to single or vice versa, can take place when the machine is working, without any load interruption. Substitution takes place smoothly, and if the gas fuel supply system has been normal again then the fuel system will switch to dual fuel system again.
And when the gas valve is opened, the gas will go to the air/gas mixer to be mixed with air that will enter the combustion chamber. The air mixture with the fuel gas enters through the inlet valve. The combustion process is executed shortly after the diesel oil is injected by the fuel nozzle at the end of the compression process. It is at this time that the volume of air mixture with the gas increases with the high temperature and pressure when the piston approaches the position of the top dead point. Fuel oil that serves as pilot-ignited is injected in small amounts under high pressure. [Semin, Rosyida]

Table 6. Percentage of Fuel Consumption

Percentage of Fuel		**FOC/trip (Kg)**	**LHV_{fuel} (MJ/kg)**	**LHV_{engine} (MJ)**	**Massa (Kg)**	**$\sum Mass_{CNG}$ (m^3)**	**∑CNG Cyl. *)**
scenario 1	40% HSD	18759.6	44	330169.0	7503.8	-	18
	60% CNG		45.8	515513.8	11255.8	15633	
scenario 2	30% HSD	18759.6	44	247626.7	5627.9	-	21
	70% CNG		45.8	601432.8	13131.7	18238.5	
scenario 3	20% HSD	18759.6	44	165084.5	3751.9	-	24
	80% CNG		45.8	687351.7	15007.7	20844	
scenario 4	10% HSD	18759.6	44	82542.2	1876.0	-	27
	90% CNG		45.8	773270.7	16883.6	23449.5	

From the calculation above, it can be seen that the maximum number of CNG tubes that can be utilized to supply main engine vessels as much as 27 tubes CNG cargoes with one trip for dual fuel mode.
While the following is the design of the pipeline from the load to the main engine in the engine room.

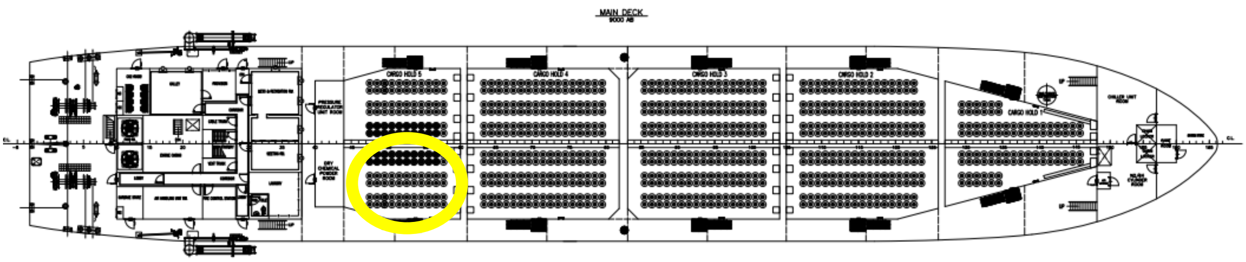

Figure 3. Cargo location for main engine

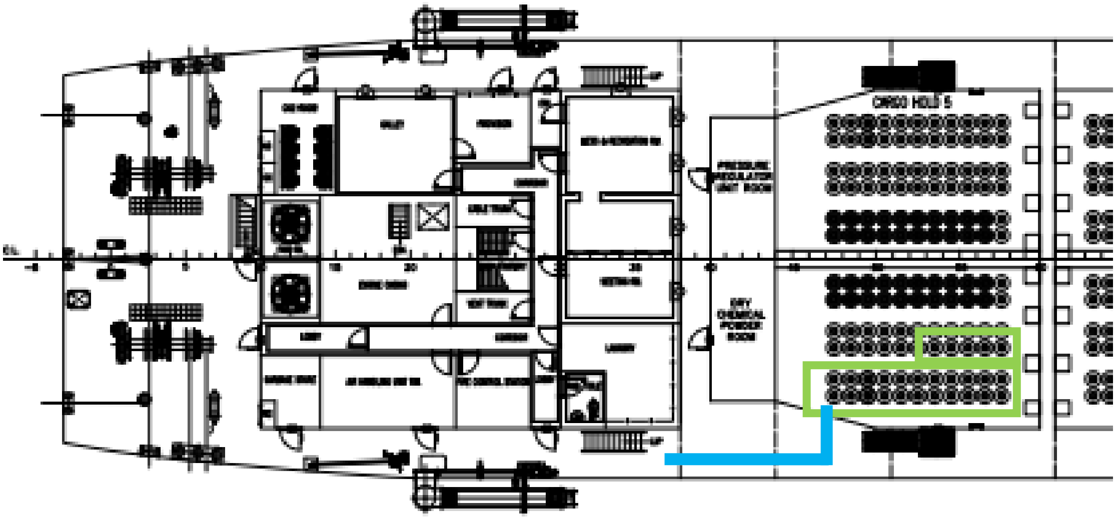

Figure 4. CNG supply system from cargoes (top view)

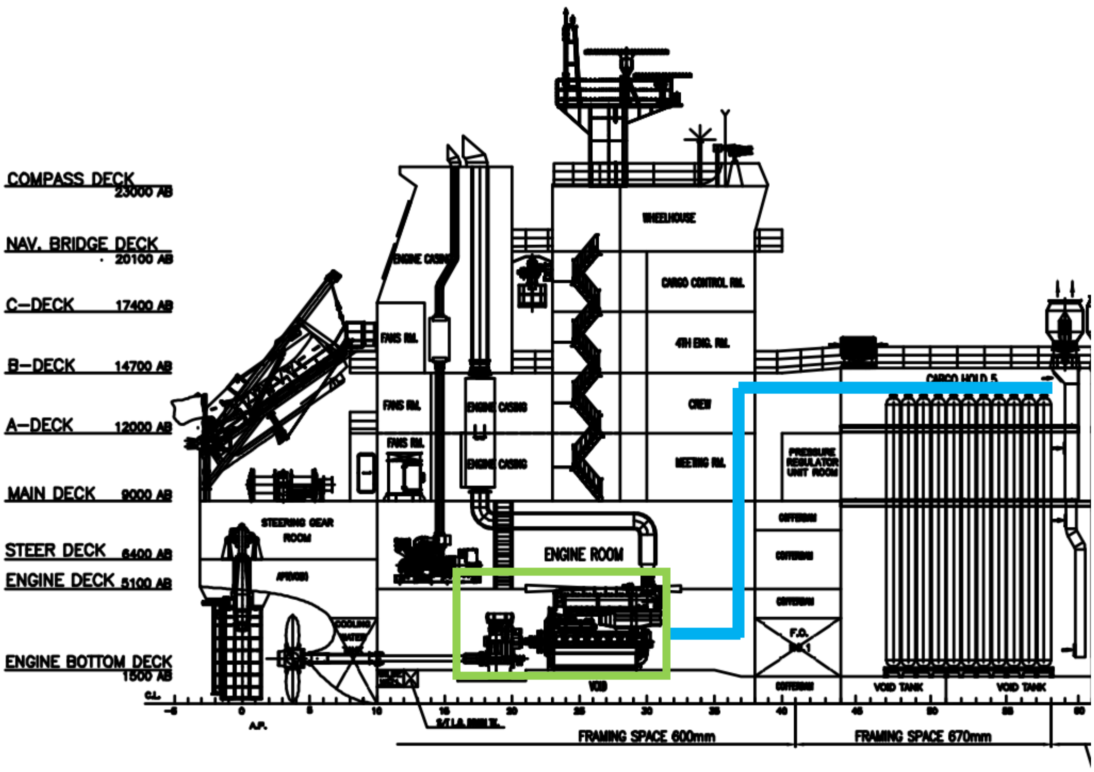

Figure 5. CNG supply system from cargoes (side view)

CONCLUSION

Using dual fuel system (HSD-CNG fuel mixture), affecting the amount of fuel required and the addition of supporting components to supply CNG fuel from the pressurized tube (cargoes) to the engine. In addition, the performance of diesel engines converted to dual fuel has decreased performance compared to using single fuel. By using the mix ratio of HSD-CNG of 40:60, 30:70, 20:80, and 10:90, in one trip CNG carrier requires about 18-27 CNG cylinder tubes.

REFERENCES

Iswantoro, Adhi., Kusuma, Indra Ranu., & Ariana, Made. (2015). Optimalisasi Penggunaan Bahan Bakar pada Mesin Induk Dual Fuel pada Kapal CNG Carrier Rute Gresik-Lombok Menggunakan Metode Multi-Objective Genetic Algorithm (MOGA). *Journal of Sains and Technology*, pp. 22-30.

Semin., Rosyida, Nur Aulia. (2017). Technical Analysis of Diesel Engine Convert to Dual Fuel (HSD-CNG) on MV. Legundi. *Interntional Journal of Marine Engineering Innovation and Research (IJMEIR)*.

Semin., Bakar. R.A. (2008). A Technical Review of Compressed Natural Gas as an Alternative Fuel for Internal Combustion Engines. *American Journal of Engineering and Applied Sciences 1*, pp. 302-311.

Semin., Dayang., Fahallah. A.Z.M., Ariana, Made., & Amiadji. (2012). Pengaruh Perubahan Compression Ratio Motor Diesel Menggunakbahan Bakar Gas dan Efeknya terhadap Power dan Daya. *National Seminar on Theory and Application of Marine Technology*.

Semin., Idris A., & Bakar. R.A., (2009). An Overview of Compressed Natural Gas as an Alternative Fuel and Malaysian Scenario. *European Journal of Scientific Research, Vol. 34, No.1*, pp.6-15.

Safer, Smater, Greener. (Future) Fuel & Fuel Converters. *Maritime Academy – DNV GL, Rev. 3.0*, pp. 13.

Steaua Romana Refinery. (2006). Marine Fuel Oil type DMB, Custom Code: 2710.19.99, Campina, Romania.

Bakar. R.A., Othman. M.F., Semin., & Ismail. A.R.. The Compressed Natural Gas (CNG) Cylinder ressure Storage Technology in Natural Gas Vehicles (NGV) Research Trends. *Faculty of Mechanical Engineering*, University Malaysia Pahang.