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# Performance Analysis of Diesel Engine Simulation Into CNG Engine

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## ABSTRACT

The fundamental problem in fuel consumption for the operation of diesel engines is in terms of costs and ensuring the availability of the fuel. The idea of using alternative fuels other than diesel fuel was increase. To overcome this, it has recommended to use natural gas because it is cheaper and has quite a lot of reserves in Indonesia. The properties of CNG and diesel oil are different, it is necessary to modify the diesel engine before using as alternative fuel. The aim of this study is to analyze the performance of diesel engines that has been modified into CNG engines connected to RPM. The analyzed performance includes brake power, brake torque, fuel consumption, and volumetric efficiency. The analysis process was carried out through a simulation using the GT-Power software. The conculsion of this study shows the use of CNG as a fuel reduces exhaust emissions even though it reduces engine performance in terms of power, torque, Break Mean Effective Pressure (BMEP), and tends to increase fuel consumption.

**Keywords :** CNG; CNG engine; Diesel Engine; HSD; Modelling

## INTRODUCTION

Diesel engines are the most widely used engines in the maritime world. However, there are problems with the use of diesel engines, including the impact on the environment and the costs required to meet the fuel oil consumption and guarantee the availability of the fuel (Orianto and Artana, 1999). Finally the idea of using alternative fuels other than fuel oil for diesel engines is also developed for otto engines. The recommendation goes to gas fuel or compressed natural gas. For several reasons, including cheaper prices, higher octane, and cleaner exhaust emissions compared to fuel oil. However, it is necessary to modify the diesel engine before it used as alternative fuel.

The performance of a diesel engine will be different as influenced by several factors, differences in fuel usage. This study was analyzed the performance of the diesel engine and the modified diesel engine that converted to use gas fuel (Ryu and Kim, 2006).

This study was analyzed the relationship between speed (RPM) and performance of diesel engines and CNG engines. The parameters used are brake power, indicated power, brake torque, BSFOC, volumetric efficiency and can be analyzed using experimental methods and or simulations. a simulation method using in this study is the GT-POWER software as part of the GT-SUITE.

The aims of this study are developing computer models for diesel engines and CNG engine, analyzing the effect of changing diesel engine to CNG engine and the effect of using gas fuel as a substitute for diesel fuel on engine performance.

### Diesel Engine

Diesel motors generally use liquid fuel that injected into the combustion chamber or can be used in the initial combustion chamber using an injection pump. Diesel motors are commonly called compression ignition engines. The combustion air is compressed and then followed by fuel injectionto start combustion process (Sukoco and Arifin, 2008).

### HSD and Compressed Natural Gas

Diesel oil is a type of fuel that is generally used in all types of high speed diesel engines. Diesel oil is also commonly referred to as gas oil, automotive

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diesel, high speed diesel. Physically diesel oil is dark yellow in color and clear.

Natural gas was produced from gas wells or mixed with crude oil through oil wells. Most of the constituents of natural gas is methane. Natural gas can be stored in compressed form (compressed natural gas) or in liquid (LNG). LNG requires a refrigeration system and cryogenic tank.

Compressed natural gas doesn't require expensive refrigeration systems and cryogenic tanks. Compressed natural gas requires a larger volume to store when compared to LNG for the same mass. The main components in natural gas are methane (CH4) 80-95%, ethane (C2H6) 5-15%, propane (C3H8) and butane (C4H10) less than 5%, gas containing sulfur and helium gas (Bakar and Ismail, 2009).

The biggest problem focus of internal combustion engines is the effect on the environment and fuel consumption. Otto or diesel engines are commonly used to generate power. Finally, a new design is needed, which requires research and technology to find new designs or components so that these machines can use gas fuel.

**CNG Engine**

Research on CNG engines has grown in the past decade, motivated by economics, emissions, and the best strategy in finding alternative fuels other than fuel oil. There are five attractive reasons for CNG as a fuel such as :

1. It is a fuel that is cheaper than fuel oil such as diesel and gasoline
2. Lower exhaust emissions than fuel oil such as diesel and gasoline
3. Emissions of gases that trigger the greenhouse effect are lower than fuel oils such as diesel and gasoline
4. Save fuel oil consumption.
5. There are many natural gas reserves in the world. (Kim et al. 2008).

Table 1. Characteristics of CNG

| CNG Characteristics | Value |
|---|---|
| Vapour density | 0.68 |
| Auto Ignition | 700°C |
| Octane rating | 130 |
| Boiling point (Atm. Press) | -162°C |
| Air-Fuel Ratio (Weight) | 17.24 |
| Chemical Reaction With Rubber | No |
| Storage Pressure | 20.6Mpa |
| Fuel Air Mixture Quality | Good |
| Pollution CO-HC-NOx | Very Low |
| Flame Speed m per sec | 0.63 |
| Combust. ability with air | 4-14% |

In CNG engines that use gas fuel, combustion is assisted by spark plugs or heating coils (spark) which replace the fuelling equipment from the diesel engine. The gas fuel entering the combustion chamber has been mixed with air before entering the combustion chamber through the injection port. The entry of fuel and air when the piston moves from Top Dead Centre (TDC) to Bottom Dead Centre (BDC). The pistons must be modified to reduce the compression ratio and must be accompanied by a high-energy ignition system. The system suitable for gas fuel is ideally a suitable timed port injection system. The analyzing it, GT-POWER software is used to simulate and analyze the process (Bruce, 1993).

The usual changes and additions that must be made in modifying a diesel motor into a CNG engine include :

1. Addition of an injector port on the intake manifold because fuel is not directly entered into the combustion chamber. So the fuel is mixed with air before it enters the cylinder. The installation of this injector port is expected to improve fuel efficiency.
2. Replacing the injector from a diesel motor and modified by putting a spark plug or spark. Because the CNG engine, the combustion process is assisted by spark plugs. The spark plug itself is one of the spare parts installed in the cylinder head which is equipped with electrodes. As in the following picture. In the center of the spark plug there is an electrode that is connected by a cable to the ignition coil outside the spark plug. The spark plug is connected to a voltage of thousands of volts generated by the heating coil. The electric voltage from the ignition coil produces a voltage difference between the electrode in the center of the spark plug and the side. Current cannot flow because the gas and air entering the combustion chamber are insulators, but the greater the voltage difference, the gas and air structure between the two electrodes changes. When the voltage exceeds the dielectric strength of the gas present, the gas mixed with the air is ionized and which was an insulator, turns into a conductor. After that the electron current can flow and with the flow of electrons, the temperature in the spark plug gap increases dramatically to 60,000 K. This very high temperature causes the ionized gas to expand rapidly.
3. Reducing the compression ratio, because the octane value of CNG is higher than the octane rating of diesel fuel. The compression ratio can be reduced to above 16: 1. The compression ratio is the ratio between the volume of the combustion

chamber plus the volume of the cylinder when the piston is at BDC with the volume of the combustion chamber when the piston is at TDC.

The modifications has been done to accommodate gas fuel, it eventually shortens the ignition delay.

**Engine Performance**

Each engine certainly has a different performance depending on the type of fuel and the combustion process.

Table 1 shows the octane rating of CNG is around 130, meaning that the CNG engine should operate with a compression ratio above 16:1 without "knock" or detonation. It will increase thermal efficiency up to 10% over gasoline. In terms of emissions, CNG reduces $CO_2$ emissions by 20-25% when compared to gasoline. When the engine operates with gas fuel, the output power of the engine will decrease. The natural gas has a low cetane value, so this engine requires spark as previously described (Goto, 1999).

The characteristics of the CNG engine in general include geometric characteristics consisting of compression ratio and bore stroke ratio and the ratio of connection rod length to crank radius, brake torque and power, indicated work per cycle, mechanical efficiency, mean effective pressure, specific gas consumption efficiency, air/fuel and fuel/air ratio, and volumetric efficiency.

**GT-Power**

GT-POWER is one of the six components in the GT-Suite. Where GT-POWER is used to simulate the performance analysis of the engine with complete control capabilities. GT –POWER is the standard engine simulation tool in the industry, which is widely used by engine and vehicle manufacturers as well as their suppliers.

## RESEARCH METHODS

The engine component dimensions needed in developing model for simulation. The diesel motor used is Yanmar L100 with general dimensions as follows:

- Merk : Yanmar
- Model : L100
- Bore : 86.0 mm
- Stroke : 70.0 mm
- Displacement : 406.0 cc
- Compression ratio : 20.28
- Intake valve close : 469 CA
- Intake valve open : 361 CA
- Exhaust valve open : 191 CA
- Exhaust valve close : 325 CA
- Ignition system : Compression
- Fuel intake system : Direct Injection
- Fuel : HSD

**Simulation Parameters**

The simulation parameter required is the size of the diesel motor component requested by the software. Which starts from the intake system, on the engine cylinder and injection system, and on the exhaust system.

The software used in developing the model is GT-Power which is part of the GT-Suite. The first model made was a model before the diesel motor modified into a CNG Engine. There are three systems has been modeled including the intake system, the engine cylinder, and fuel injection system. The last step is modifying the model which was originally still a diesel motor into a CNG Engine with the same three system sequences.

**Simulation Validation**

At this stage the unmodified model is compared with the parameters of the Yanmar L100 diesel motor. The modeling needs to be repeated from determining the simulation parameters until match with the actual parameters. Finally, the model of the CNG Engine adjusts.

**Output Analysis and Presentation**

The analyzed are torque, power, fuel consumption, volumetric efficiency, all of which are based on rotational speeds of 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000 rpm. Then the results of the diesel and CNG engine models was compared and analyzed. The last was determine the recommendations that useful in modifying the diesel motor to the CNG Engine.

## RESULTS

**Brake Power (kW)**

Figure 1 above showed the power performance of the CNG engine was lower than the power of the diesel engine. The highest value for the diesel engine was 6.62 kW at 3500 rpm and the highest value for the CNG engine was 3.83 kW at 2500 kW. The use of CNG as fuel will reduce the power of the engine by up to 42%.

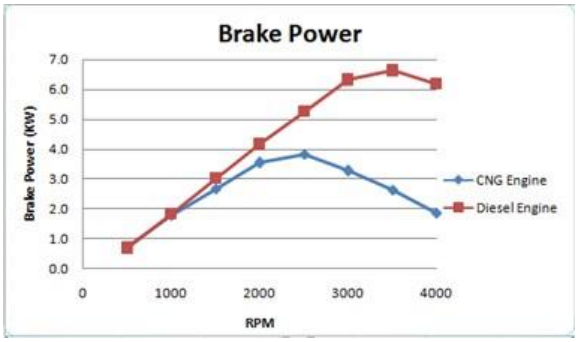


Figure 1. Graph of CNG engine brake power against diesel engine

## Indicated Power (kW)

Figure 2 showed the power performance of the CNG engine is lower than the power of the diesel engine. The highest value for the diesel engine is 8.49 kW at 3500 rpm, and the highest value for the CNG engine is at 4.82 kW at 2500 kW conditions. The use of CNG as fuel will reduce the power of the engine by up to 43%.


Figure 2. Graph of CNG engine power indicated against diesel engine

## Brake Torque (N-m)

Figure 3 showed the torque performance of the CNG engine is lower than the torque of the diesel engine. The highest value for the diesel engine is 20.09 N-m at 3000 rpm and the highest value for the CNG engine is 17.13 N-m at 1000 kW. The use of CNG as fuel will reduce the power of the engine up to 14.7%.

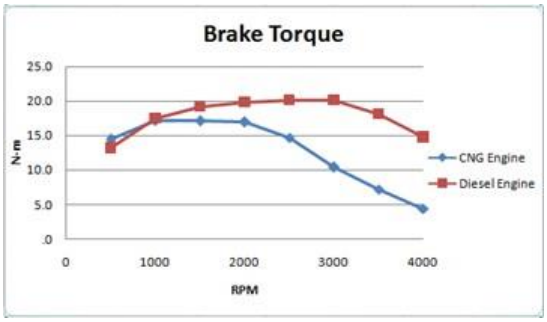


Figure 3. Graph of Brake Torque CNG Engine Against Diesel Engine

## Indicated Torque (N-m)

Figure 4 showed the torque performance of the CNG engine is lower than the torque of the diesel engine. The highest value for the diesel engine is 24.67 N-m at 3000 rpm. The highest value for the CNG engine is 20.48 N-m at 2000 kW. The CNG reduce the power of the engine up to 16.9%.

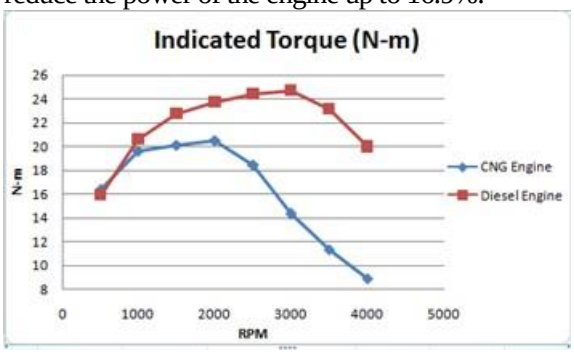


Figure 4. Graph of CNG Engine Indicated Torque Against Diesel Engine

## Brake Specific Fuel Consumption (g/kW-h)

The start of low rotation, the fuel consumption of the CNG engine is lower than that of the diesel engine. At 2500 rpm, the fuel consumption of the CNG engine is greater than the fuel consumption of the diesel engine and continues to increase in maximum speed. Figure 5 showed the graph of brake specific fuel comsumption. The average fuel consumption of the CNG engine is 322.36 g/kW-h and the average fuel consumption of the diesel engine is 244.59 g/kW-h. So the use of CNG as a fuel increases fuel consumption on average by 24%.

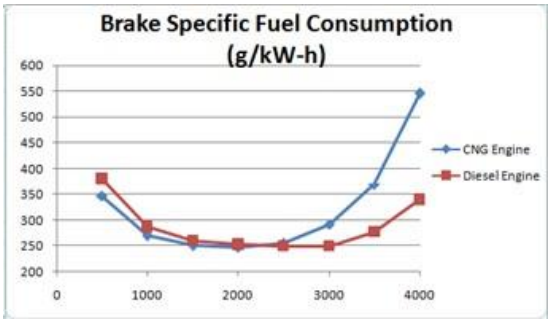


Figure 5. Graph of Brake Specific Fuel Consumption of CNG Engine on Diesel Engine

**Brake Mean Effective Pressure (Bar)**

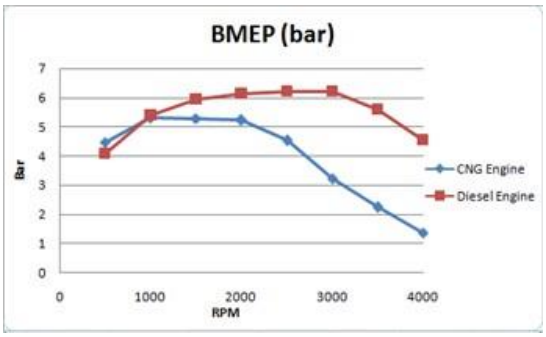


Figure 6. Graph of Brake Mean Effective Pressure of CNG Engine against Diesel Engine

Figure 6 showed the early rounds the average pressure of the CNG engine is higher than that of the diesel engine, but the trend of the average pressure curve for the CNG engine is lower than that of the diesel engine. The average BMEP value for the CNG engine is 3.94 bar and for the diesel engine it is 5.51 bar. So, the use of CNG as a fuel can reduce BMEp up to 28.49%.

**Cylinder Maxium Temperatur (K)**

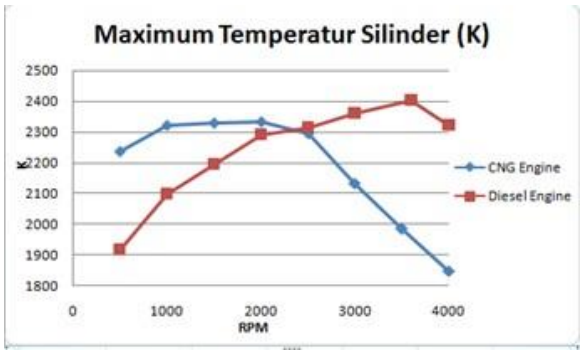


Figure 7. Graph of Maximum Cylinder Temperature of CNG Engine against Diesel Engine

In Figure 7, the cylinder temperature of the CNG engine is higher than the diesel engine in initial speed. The cylinder temperature of the CNG engine moves down and is lower than the diesel engine which showed an increasing trend in its curve. The average value of the cylinder temperature for the CNG engine is 2185 K and the diesel engine is 2240 K. The use of CNG as a fuel results in a decrease in temperature of up to 2.4%.

**Brake Specifi Nox (g/kW-h)**

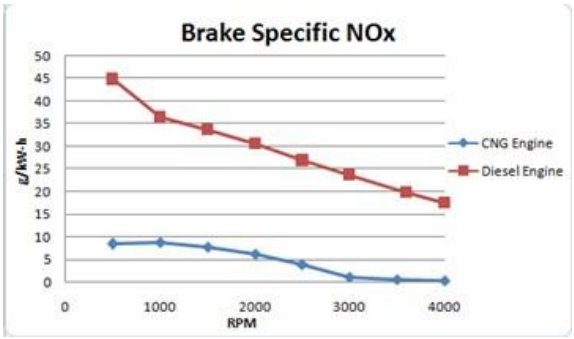


Figure 8. Graph of Brake Specific Nox CNG Engine against Diesel Engine

In Figure 8, the NOx emission from the CNG engine is far below the NOx emission from the diesel engine. The average value of the brake specific NOx CNG engine is 4.58 g/kW-h and the average value for the diesel engine is 29.1 g/kW-h. The use of CNG as a fuel reduces the level of NOx emissions by up to 84% in terms of brake specific NOx.

**NOx Concentration (ppm)**

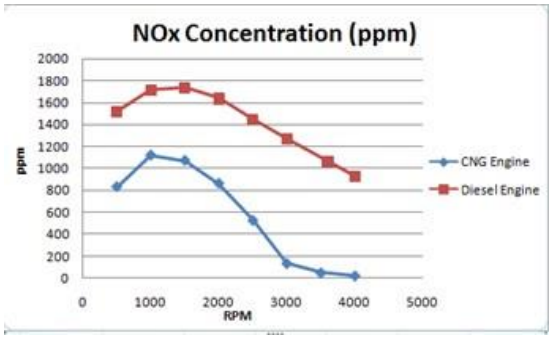


Figure 9. Graph of NOx Concentration of CNG Engine against Diesel Engine

Figure 9 showed the NOx emission from the CNG engine is far below the NOx emission from the diesel engine. The average value of the NOx concentration from the CNG engine is 577.24 ppm and the average value for the diesel engine is 1415.8 ppm. The use of CNG as a fuel reduces the level of NOx emissions by up to 59% in terms of the NOx concentration in ppm.

**Brake Specific Soot (g/kW-h)**

From Figure 10, there is no soot emission produced by the CNG engine. In contrast to diesel engines, emissions contain soot and tend to increase by engine speed. The gas fuel can reduce soot emissions up to 100%.

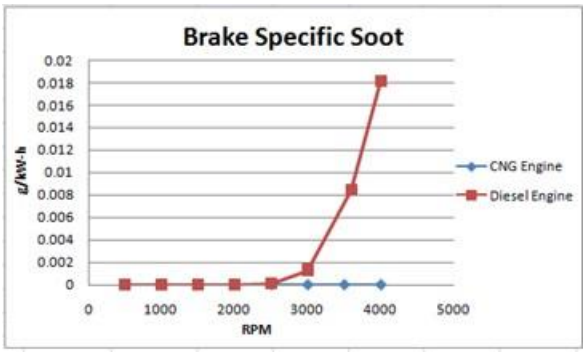


Figure 10. Graph of Brake Specific Soot CNG Engine against Diesel Engine

**Soot Concentration (ppm)**

Figure 11 showed there is no soot emission produced by the CNG engine. In contrast to diesel engines, emissions contain soot and tend to increase by engine speed. The gas fuel can reduce soot emissions by up to 100%.

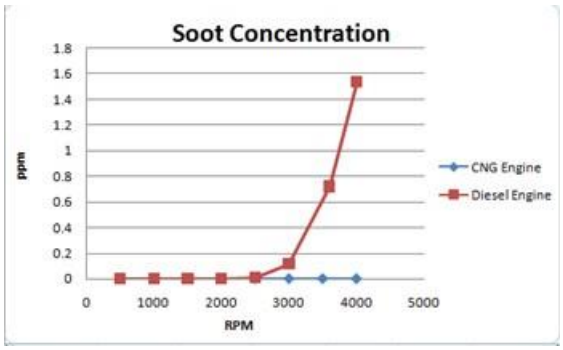


Figure 11. Graph of CNG Engine Soot Concentration against Diesel Engine

## CONCLUSIONS

The models for diesel engines and CNG engines have been completed. The CNG fuel reduces power up to 42% in terms of brake power and 43% in terms of indicated power, reduces torque up to 14.7% in terms of brake torque and 16.9% in terms of indicated torque, increases the average fuel consumption of the engine by 24%, decrease in BMEP of up to 28.49%, decrease in the maximum cylinder temperature of up to 2.4%, reduces exhaust emissions for NOx by up to 84% in terms of brake specific NOx and 59% in terms of NOx concentration. The CNG fuel in CNG engine reduces exhaust emissions for soot by up to 100% in terms of brake specific soot and soot concentration compare to diesel engine.

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