

## Performance Investigation of Dual Fuel Engine: A Technical Review

Semin and Nilam S. Octaviani

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

**Abstract:** The concerns about the diesel engine's emissions and the reduced availability of fuel oil, led to the adoption of alternative fuels on diesel engines have been found to be an attractive solution. The application of natural gas is a very promising and very attractive because of its abundant availability in nature, low cost and clean burning quality for use as an alternative fuel on compression ignition engine. The purpose of this study is to explain the working principle of dual fuel engines. In this technical study, will be discussed performance of dual fuel engine and compared with diesel engine. Based on the literature, it has been found that engine power and engine torque decrease in dual fuel mode but power loss can be reduced or recovered by changing some operating parameters. Brake Thermal Efficiency (BTE) in dual fuel mode is lower at low and medium loads while under high engine load conditions, equal to or slightly higher when compared to normal diesel mode.

**Key words:** Alternative fuel, dual fuel, engine performance, natural gas, BTE, diesel

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### INTRODUCTION

Natural gas is an alternative fuel with the main constituent components of methane gas ( $\text{CH}_4$ ) with a composition of 87-96% (Semin, 2008; Wei and Geng, 2016; Wang *et al.*, 2016) and the remainder are other components such as ethane, propane, n-butane isobutane, n-pentaneane isopentane, hexane,  $\text{CO}_2$ , nitrogen,  $\text{O}_2$  and little hydrogen content. Availability of natural gas reserves is still abundant with relatively cheaper price compared to gasoline and diesel but its utilization has not been done optimally (Semin, 2008; Arif and Sudarmanta, 2015). And according to Wei *et al.* (2015) natural gas is environmentally friendly fuel because it contains less carbon per unit of energy compared to fossil fuels. In addition, natural gas also generates less  $\text{CO}_2$  emissions within every mile of the engine trip, thereby reducing the effect of greenhouse effect caused by  $\text{CO}_2$  gas.

According to Semin (2008), Semin and Bakar (2013) Compressed Natural Gas (CNG) natural gas has been widely developed as fuel for spark ignition engines but for diesel engines it still needs a lot of study and development. Diesel engines are widely used in the world due to their high combustion efficiency, reliability, adaptability and cost-effectiveness (Bayraktar, 2008; Wei *et al.*, 2015). However, diesel engines are one of the major contributors to environmental pollutions (Torregrosa *et al.*, 2013;

Tutak *et al.*, 2015). The emission particles have extremely harmful effects on human health and environment.

Base on Zoltoski (2014), natural gas will be difficult to apply to diesel engines because natural gas is a type of fuel with low cetane number but high octan number. However, Semin (2008) explained that the natural gas can be applied to diesel engines with dual fuel technology where in the engine is operated on lean burn combustion with a small amount of diesel fuel. In dual fuel diesel engines, natural gas acts as the main fuel and diesel fuel acts as a pilot fuel.

Research and development of dual fuel diesel engines is increasing every year not only used for experimental processes but also has been developed in the field of industry and transportation (JFEE., 2014; Ehsan and Bhuiyan, 2009; Zhang *et al.*, 2015; Bakar *et al.*, 2007), the applications of natural gas as alternative fuel are very promising in the environmental and economic points of view but technically it is constrained on performance degradation of power, torque and brake thermal efficiency (Zoltoski, 2014; Ehsan and Bhuiyan, 2009).

The main purpose of this study is to provide a comprehensive review of the literatures relate to the application of natural gas as fuel on diesel engine. In this review, the performance characteristic is discussed to get a clear understanding of the natural gas/diesel dual fuel engine.

## MATERIALS AND METHODS

**Dual fuel concept:** The diesel engines, today have undergone various developments. One of them is the conversion of fuel used which previously used liquid fuels (HFO, MDO and HSD) as main fuel, now uses mixing between natural gas fuels and liquid fuels. This type of diesel engine is better known as dual fuel engine. Dual fuel engine is a diesel engine that uses gas and diesel fuel with a certain composition ratio. Gas acts as the main fuel while diesel fuel acts as a pilot fuel.

The dual fuel engine working principle is a combination of the working principle of conventional diesel engines and otto engines. In a diesel engine, the air is compressed in the combustion chamber until it reaches a certain pressure and temperature then the fuel is injected into the combustion chamber resulting in combustion. While on the engine otto, fuel and air mixing first in the fire room and then compressed below the point of explosion and then there is combustion with the help of spark plug which acts as a pilot fuel (Heywood, 1998).

In dual fuel diesel engines, gas and air are mixing when they enter the combustion chamber. Gas and air that have been mixed then experience the compression process. At the end of the compression process when the gases and air have been at a certain pressure and temperature, a small amount of diesel fuel is injected to cause the combustion process. Figure 1 illustrates the dual fuel engine diagram (Sun *et al.*, 2015). The advantage of this type of engine is if there is a failure in gas fuel, the

engine can still work by switching dual fuel mode into a conventional diesel engine mode that only rely on diesel fuel. While the drawback is the engine is very dependent on the availability of diesel fuel for dual fuel diesel engine working system is still going on (Sahoo *et al.*, 2009).

**Performance characteristics:** Performance is the main parameter of an engine. Engine power, torque and Brake Thermal Efficiency (BTE) are very important performance indicators. These indicators will be reviewed down below.

**Engine power:** Engine power is the most important performance indicators of engine. This indicator shows the working ability of the engine. Mehta *et al.* (2015) compared the power efficiency of diesel engines and dual fuel engines to variations in load and rotation variations. Simulation results show the higher the load given, the power efficiency of the diesel engine has increased. The results are contrary to the dual fuel engine, the greater the load given to the engine, the engine efficiency further down. This comparison shows that engine operating in dual fuel mode have a smaller power efficiency when compared to diesel engines operated in normal mode.

Bakar *et al.* (2007) simulated a four-stroke diesel engine, single cylinder and fueled by diesel and CNG. One-dimensional CFD GT-Power simulation is used as a tool to obtain the power output. The result shows that maximum power in diesel engines operated with CNG fuel are smaller when compared to diesel fuel-operated

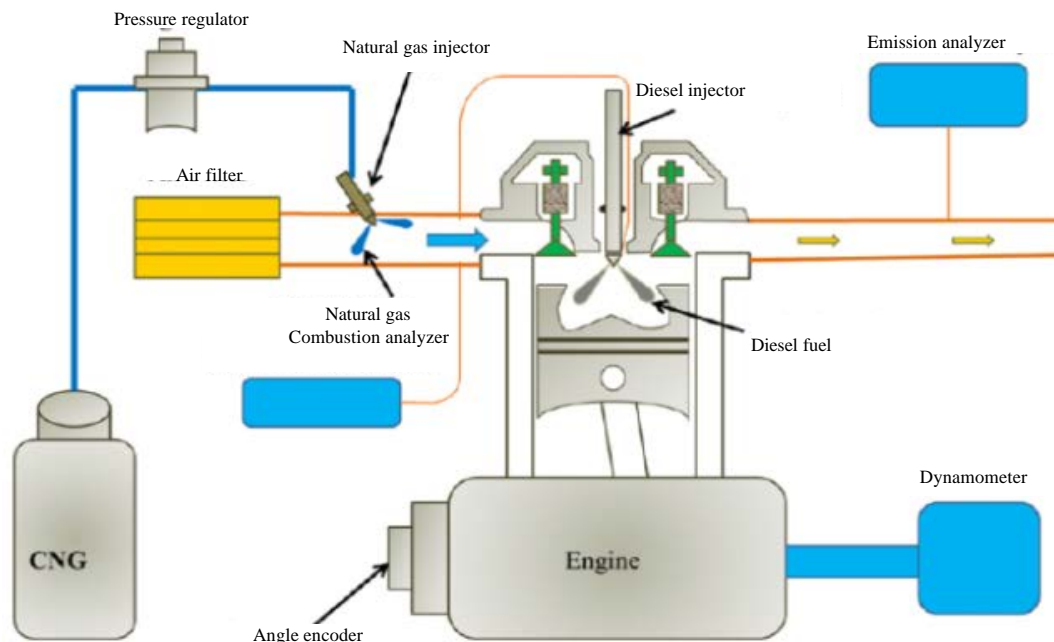


Fig. 1: The schematic diagram of dual fuel engine system (Sun *et al.*, 2015)

engines. It was found successively that the maximum power decreased by 44% when the engine operated using CNG. Base on the simulation, the researchers are recommended to make some modifications on the engine to improve the operational parameters.

Semin *et al.* (2016a, b) investigated the power performance characteristics of gas engine using new injector. The gas injector had been modified became multi-holes of nozzle diameter and multi-degree of nozzle hole. The result was presented that the best angle of nozzle hole and the excellent diameter of nozzle hole were 25° and 3.0 mm, respectively compared to the other angle of nozzle hole and diameter of nozzle hole. They improved the fuel flow and air-fuel mixing in the combustion chamber and these parameters affected the power output. The power output went up to 8.51% by applying the new injector hole diameter.

**Engine torque:** Torque is an indicator of the thermodynamic work transferred from the chemical energy of air-fuel combustion to the mechanical energy of the piston and crankshaft. The translation movement of piston is converted into rotation movement of crankshaft. Semin *et al.* (2016a, b) investigated the effect of new injector on the torque performance characteristics of gas engine by computational modeling. The gas injector had been improved became multi-holes of nozzle diameter. The analysis of the engine performance was according to engine speed and intake valve lift variation. The study showed that the application of new injector increased the engine torque.

Liu *et al.* (2003) observed the torque of heavy duty diesel engine fueled by natural gas/diesel. The engine running under the full load condition. They concluded that the maximum torque of dual fuel operation was lower than normal diesel operation when the speed was went up.

**Brake Thermal Efficiency (BTE):** Brake thermal efficiency is an indicator of the amount of energy consumed by the engine. This indicates how efficient the input energy and it is converted into output energy (Pulkrabek, 2004). To calculate the BTE indicators, the formula that can be used is as (Heywood, 1998):

$$BTE = \frac{3600 \times P_b}{(q_{m,g} \times Q_{LHVg}) + (q_{m,d} \times Q_{LHVd})} \times 100\%$$

$P_b$  = Indicates the power output of engine (kW.  $q_{m,q}$ )  
 $q_{m,d}$  = Indicates the mass consumption of natural gas and diesel fuel (kg/h)

$Q_{LHVg}$  and  $Q_{LHVd}$  = Indicates the low heating value of natural gas and diesel fuel (kJ/kg)

Cheenkachorn *et al.* (2013) compared the BTE of diesel engine single cylinder on normal and dual fuel mode. The test conditions were carried out on a full load engine and the rotation is varied from 1100-2000 rpm. The amount of natural gas being sprayed into the combustion chamber is constant. The result, obtained that the thermal efficiency of dual fuel engine operation is smaller than the operational diesel engine during operational speed. However, at 1700 rpm engine speed, thermal engine dual fuel efficiency has decreased significantly.

Abdelaal and Hegab (2012) analyzed the thermal efficiency of dual fuel diesel and natural gas diesel engines operating at 1600 rpm and loading from 43% to above 95% of full loading. The results showed that the BTE on dual fuel mode was smaller than normal mode. However, BTE of dual fuel mode was little higher compared to normal diesel engines when the load is increased. The maximum inclining about 3% at 95% of engine full load.

By Alla *et al.* (2000, 2002) tested the effect of the amount of diesel fuel injected and the injection time on the thermal efficiency of a single cylinder diesel engine using natural gas and diesel fuel. The test results show that increasing the amount of injected diesel fuel and improving the injection timing can increase the engine's thermal efficiency value at low load, this is influenced by high pressure and temperature. However, both parameters caused knocking when the engine is operating at high load.

## RESULTS AND DISCUSSION

According to the literature review above, the performance indicators of engine namely power, torque and Brake Thermal Efficiency (BTE) under dual fuel combustion is slightly lower than normal diesel mode as shown in Table 1 (Singh *et al.*, 2007). In Table 1 FD is fossil fuel, LFCR is Liquid Fuel Consumption Rate, PGFR is producer gas flow rate and LRF is Liquid Fuel Replacement.

Table 1: Comparative performance of fossil diesel and dual fuel engine (Singh *et al.*, 2007)

Mode of operation	FD	DF	FD	DF	FD	DF
Engine load (%)	63	63	84	84	98	98
RPM of engine	1487	1490	1493	1483	1486	1489
Engine output (kW)	14.08	14.00	19.34	18.93	22.59	22.00
LFCR (kg/h)	3.586	1.336	4.517	1.445	5.370	4.183
SEC (MJ/kW/h)	11.07	19.55	10.15	15.39	10.35	11.61
$\eta_{bth}$ (%)	32.53	18.41	35.45	23.38	34.77	31
PGFR (m <sup>3</sup> /h)	-	50	-	53	-	17
LFR (%)	-	62.74	-	68.00	-	22.24
Sound pressure (dB)	100.5	96.90	101.5	102.15	99.50	100.40

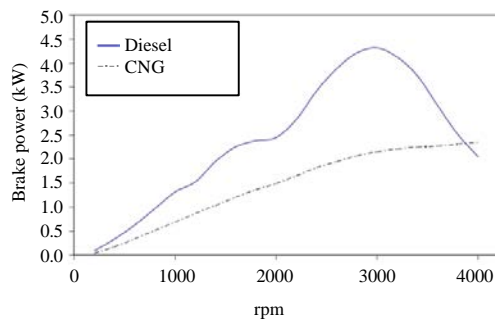


Fig. 2: Power output of diesel and CNG fuel on diesel engine (Abu Bakar and Ismail, 2007)

For the power output comparison between diesel and dual fuel using CNG are illustrated on Fig. 2. The engine speed is varied between 0-4000 rpm. The picture shows that the more power the engine speed, the more power the machine generates. Diesel fuel reaches maximum power at engine speed of 3000 rpm and CNG reaches maximum power at 4000 rpm of engine speed. Diesel fuel is capable of producing higher output power than CNG fuel when applied to diesel engines but at maximum engine speed, the power produced by diesel fuel is less than that of CNG fuel. This is caused by incomplete combustion in the combustion chamber where the air fuel ratio condition is fuel rich. Based on Semin and Bakar (2013), Semin *et al.* (2008) the another reason of the power reduction in dual fuel condition is low heating value. The low heating value of natural gas (CNG) is lower than diesel fuel. However, the problem can be solved by increasing the quantity of diesel as a pilot fuel (Imran *et al.*, 2014).

According to literature review, the BTE under dual fuel mode is little lower than normal diesel mode, especially under low load and intermediate load. While at engine high load, the BTE of engine on dual fuel mode is similar or slightly higher than normal diesel mode. The maximum inclining is 3% when the engine almost reach the full load condition. However, this condition is contrary with the BTE in the Table 1. The following reason of the BTE reduction is the combustion on dual fuel condition is very lean. It is difficult for diesel as pilot fuel to ignite and mix into air-gas mixture. Because of these condition, the lean mixture cannot be burned, so, the fuel utilization efficiency and BTE are low (Wei *et al.*, 2015).

## CONCLUSION

Problems about the environment and the energy crisis are gradually becoming more attractive to find the solutions. The application of natural gas as an alternative

fuel is very promising in environment and economy point of view but constrained on technical point of view. Based on several studies that have been done, it can be concluded that the machine operated in dual fuel mode produces a smaller engine performance than diesel engines operating in normal mode. This is due to the decrease in the amount of air entering the combustion chamber due to the addition of fuel gas. This directly decreases volumetric efficiency in the combustion chamber (Wei *et al.*, 2015). The result, resulting in a decrease in performance on dual fuel engines. To improve it an increase in the amount of diesel fuel injected into the combustion chamber increases injection pressure and improves the injection timing. However, these parameters will cause knocking when the machine is operated at high load.

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