Compressed Natural Gas Addition Effect on the Exhaust Emission of Diesel Dual Fuel Engine based on Experiment

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Abstract: Energy source availability and environmental effect from engine exhaust emission are attractive issue to be discussed recently. Furthermore, these problem are related to alternative fuel energy supply and clean energy. Natural gas is one of alternative fuel for internal combustion engine and this study will analyze the effect of Compressed Natural Gas (CNG) addition on exhaust emission of diesel dual fuel engine single cylinder. The formation of NOx, CO2 and CO will be investigated furthermore. To obtaine the data, the engine was tested on 3 different speed, they are 1500, 1800 and 2200 rpm. The gas flow rate was varied from 0-3 liter/minute on 0-4000 Watt of engine load. The experimental result indicated that the addition of CNG on diesel dual fuel engine has a significant influance on NOx, SOx, CO2 and CO emissions. NOx, Sox and CO2 emissions of diesel engine operated on dual fuel was lower than diesel engine operated on normal condition. However, the CO emission showed the different condition. It can be concluded that the implementation of CNG on diesel is a potential way to decrease the environmental effect of diesel engine combustion.

1 INTRODUCTION

Diesel engine is a type of internal combustion engine that is often used in the world because it has the best combustion efficiency, reliability, adaptability and cost-effectiveness of other types of internal combustion engines. Diesel engines also have high reliability with relatively low operational costs. Diesel engines are also used as the main engine of the ship, using fossil fuel such as heavy fuel oil (HFO), marine diesel oil (MDO) dan high speed diesel (HSD). However, the emissions from combustion of these fuels contain gases that are harmful to the environment and human health.

In recent years, International Maritime Organization (IMO) has implemented increasingly stringent emission limits produced by ships. In IMO Tier III, NOx emissions from ships should be reduced by more than 75%. This forces machine manufacturers and researcher to advance the steps for reducing emissions while trying to maintain high efficiency. Some techniques, especially proven in the automotive field are reconsidered and evaluated for their emission reduction potential. Several emission reduction techniques have been carried out. However, some of them are only able to reduce certain emissions. For example, the application of Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR) on diesel engines can only reduce NOx emission (Hussain, et.al, 2012; Komar, et.al, 2007). On the other hand, the application of natural gas as an alternative fuel is one way to reduce ship exhaust emissions, and the results of this research show that it can reduce emissions of NOx, SOx, CO2 and PM simultaneously (Ohashi, 2015).

Natural gas is an alternative fuel with the main constituent components of methane gas (CH4) with a composition of 87-96% (Semin and Bakar, 2008; Wei, 2016; Wang, et.al, 2016) and the remainder are other components, such as ethane, propane , n-butane, isobutane, n-pentaneane, isopentane, hexane, CO2, nitrogen, O2, 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 and Bakar, 2008; Wei, 2016; Wang, et.al, 2016; Arif and Sudarmanta, 2015). And according to Wei et al (2016) 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 CO2 emissions within every mile of the

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engine trip, thereby reducing the effect of greenhouse effect caused by CO2 gas.

According to Semin et al (Ohashi, 2015; Semin and Bakar, 2013), compressed natural gas (CNG) has been widely developed as fuel for spark ignition engines, however for diesel engines, CNG still needs a lot of study and development. Base on Zoltowski (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 et al (2008, 2016, 2016) explained that the natural gas can be applied to diesel engines with dual fuel technology where 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, they are not only used for experimental processes but also has been developed in the field of industry and transportation (JFE, 2014; Mehta, et.al, 2015; Semin, et.al, 2007; Ehsan and Bhuiyan, 2009), the applications of natural gas as alternative fuel are very promising in the environmental and economic points of view even though technically constrained on performance degradation (Zoltoski, 2014; Ehsan and Bhuiyan, 2009).

The main purpose of this investigation is to validate the effect of natural gas application on diesel engine, specially exhaust gas emission. The main exhaust gas emission will be investigated are NOx, CO and CO2.

2 LITERATURE REVIEW

2.1 Dual Fuel Concept

Nowadays, diesel engines come with various developments, one of which is a dual fuel system. The dual fuel system is a diesel engine system using dual fuel (diesel and gas fuel) in the combustion process. Diesel engines use a dual fuel system commonly referred to as a dual fuel diesel engine. In two-fuel diesel engines, gas acts as the main fuel while diesel acts as pilot fuel.

The dual fuel engine working principle is the combination of the 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 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. 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).

2.2 Emission

2.2.1 Nitrogen Oxides (NOx)

NOX is one of the most detrimental emissions from diesel engines and it is a grouped emission consisting of nitrogen monoxide (NO) and nitrogen dioxide (NO2). NO is the main component and usually accounts for more than 90% of NOX emissions in engine cylinders. The formation of NO in the combustion zone is a chemical complex and two distinct mechanisms are involved, namely, the thermal mechanism (Zeldovich mechanism) and the fast mechanism (Fenimore mechanism).

According to thermal mechanism, the formation of thermal NO is strongly influenced by the in-cylinder temperature and oxygen concentration. NO formation occurs when temperatures above about 1800 K and formation rates increase exponentially with an increase in in-cylinder temperature (Heywood, 1998). According to a prompt mechanism, formation the NO prompt is led by intermediate hydrocarbon fragments from combustion of fuel - specifically CH and CH2 - reacting with N2 in the combustion chamber and the resulting C-N species then continues through a reaction pathway involving O2 to produce NO (Hoekman and Robbins, 2012).

NO prompt is usually only formed under fuel-rich conditions, where a number of hydrocarbons are available to react with N2. The prompt NO has a relatively weak temperature dependence compared to thermal NO (Fenimore, 1971; Stiesch, 2003). Under most conditions of combustion of diesel engines, thermal mechanisms are believed to be the main contributors to total NOx (Bowman, 1979; Fernando, 2006).

2.2.2 Carbon Monoxides (CO)

Carbon monoxide (CO) is a type of harmful emission that is different from the engine and its function in the availability of fuel in combustion and combustion temperature in the cylinder, which controls the rate of decomposition of fuel and oxidation (Heywood, 1998). Higher CO usually results from lack of oxygen. However, large amounts of CO can also be produced in fuel areas when the combustion temperature is less than 1450 K (Kitamura, et.al, 2002).

2.2.3 Carbon Dioxides (CO2)

Carbon dioxide (CO2) is a product of hydrocarbon fuels that are completely burned. The first hydrocarbon fuel is oxidized to CO during the combustion process. And then if the temperature in the cylinder is high enough and in the presence of oxygen, CO is oxidized to form CO2 in sequence. Thus, the formation of CO2 is very dependent on the in-cylinder temperature and oxygen concentration.

3 EXPERIMENTAL SET-UP

3.1 Fuel Properties

Compressed Natural Gas (CNG) is an alternative fuel that can be used as a substitute for gasoline, diesel fuel and propane / LPG. CNG is a gas with the main composition is methane (CH4). In addition, propane, butane, iso-butane and other gases are also contained in small quantities. Usually the methane gas content is more than 90-98% in natural gas, depending on the location of the source and process of natural gas processing.

Table 1: The Characteristic of Compressed Natural Gas (Wei, 2016).

Properties	Value
Density (kg/m^3)	0,72
Flammability limits (volume % in air)	4,3-15
Flammability limits (Ø)	0,4-1,6
Autoignition temperature in air (^{0}C)	723
Minimum ignition energy (mJ)	0.28
Flame velocity (ms-1)	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 (MJ/kg)	45.8
Heat of combustion (MJ/kg air)	2.9

The addition of gas as fuel in diesel engines causes the addition of new components and modifications to several engine components. Tiwari (Tiwari, 2015), conducted an experiment in converting diesel engines into dual fuel engines using diesel and gas (CNG) fuel. Some system components that need to be modified include the cylinder head, spark ignition system and cooling system. While the components that need to be added to the modification process are selenoid valves, diesel modulators, high / low pressure filters, the use of low compression type pistons, dual fuel Electronic Control Units (ECUs) and turbocharger air bypass (TAB). The last is the addition of components to the gas installation system so that it can be injected into the combustion chamber.

Several studies on the conversion of diesel engines fueled by diesel oil to dual fuel engines (diesel and gas) have been carried out, both in computational and experimental simulations (Heywood, 1998; Sahoo, et.al, 2009; Semin, et.al, 2009; Tesfa, et.al, 2013). The conversion results have an effect on the exhaust emission. This is due to differences in the characteristics of the fuel used. Table 2 shows the differences in properties between gas and diesel fuel. It is the difference in property of this fuel that causes the addition of natural gas in the combustion chamber to affect the change in exhaust emission in dual fuel engines.

Table 2: Physicochemical properties of natural gas and diesel fuel (Sahoo, et.al, 2009).

Fuel Properties	Natural Gas	Diesel
Low heating value (MJ/kg)	48.6	42.5
Heating value of stoichiometric mixture (MJ/kg)	2.67	2.79
Cetane number	-	52.1
Octane number	130	-
Auto-ignition temperature (^{o}c)	650	180-220
Stoichiometric air/fuel ratio	17.2	14.3
Carbon content (%)	75	87

3.2 Engine Set-up

The engine used in the experiments is a single-cylinder, four-stroke, water-cooled, direct injection (DI) compression-ignition engine. Dimensions of the engine are the bore D = 85 mm and stroke H = 87 mm. The main specifications of the engine are presented in Table 2. The shaft of the engine is coupled to the rotor of an electric generator which is used to load engine by receiving the field voltage. A calibrated burette and a stopwatch were employed to measure the mass flow rate of fuel.

Table 3: Main Specification.

Engine Specification	Data
Engine type	Four stroke cycle, Direct injection
Number of cylinder	1
Bore x Stroke	85 mm x 87 mm
Displacement	493 cc
Compression Ratio	18
Max. Engine speed at full load	2200 RPM
Continues Power Output	7.5 kW
Specific Fuel Consumption	171 gr/HP.h
Volume per injection	0.07 mL

Data retrieval is performed on diesel engines in normal conditions and in fuel mode. The engine is operated at 1800, 2000 and 2200 rpm with a variation of the 0-4000 Watt electric load. In dual fuel systems, the gas is injected into the intake manifold at 20° BTDC at the exhaust stage or in conjunction with the opening of the suction valve. While diesel fuel is injected into the combustion chamber according to the engine conditions, namely at 18° BTDC on the compression stage. Gas fuel entering the combustion chamber is regulated in 1-3 litre / minute variations. Experimental set-up of this study is presented on Figure 1.

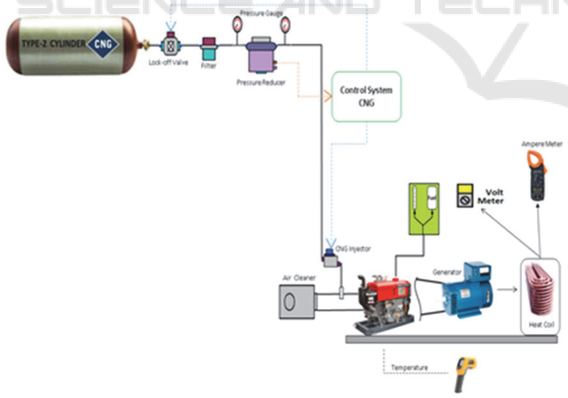

Figure 1: Experimental Engine Set-up.

4 DISCUSSION

4.1 Nitrogen Oxide (NOx)

The addition of CNG to the diesel engine combustion process affects the NOx emissions produced by the engine. When the engine was operated in normal mode using diesel fuel, NOx emissions generated from the combustion process are as much as 871 ppm. However, the amount gradually decreases as the CGN is added to the combustion chamber. At 25% engine load, the reduction of NOx as a result of adding a number of CNG is between 50-65%.

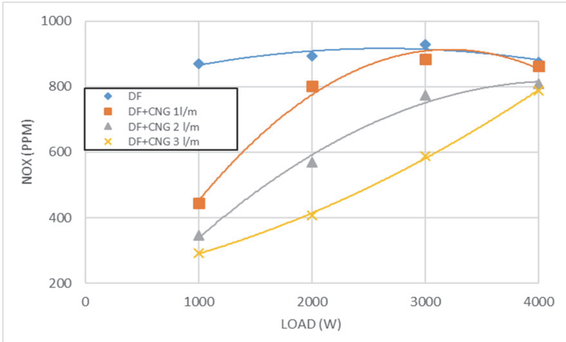

Figure 2: Effect of CNG addition and engine load on NOx Emission.

According to Figure 2, engine load also affects NOx emission. When the engine was operated in normal mode, the amount of NOx rise along with the increase of engine load and it reaches the maximum value when the engine operates on the 75% engine load before finally returning down at maximum load. On the other hand, when the engine operates in dual fuel mode, NOx emissions generated increase with the increasing of engine load. When engine operating on dual fuel mode at 100% of engine load, the NOx value is almost equivalent to the engine when operating in normal mode.

The addition of CNG in the combustion process increases the heat capacity of the air mixture, CNG and diesel fuel in-cylinder which results in a reduction in the average temperature at the end of the compression step and during the overall combustion process. Low combustion temperature affects the decrease in NOx formation. At lower engine loads, the resulting combustion temperature is very low so that a decrease in NOx on the engine low load occurs significantly (Wei, 2016). This event is shown in Figure 2. Longer ignition delay from combustion of natural gas / diesel double fuel due to differences in properties of both fuels and the poor quality of combustion of natural gas caused by lean premix conditions will reduce combustion temperature, resulting in a reduction in NOx emissions

The effect of engine speed on the amount of NOx can be seen in Figure 3. When the engine operates in normal mode, NOx drops when the engine speed increases. While dual fuel mode experiences the opposite. On diesel engine operation, the increase in engine speed, NOX formation time becomes reduced, and hence NOX emissions decrease.

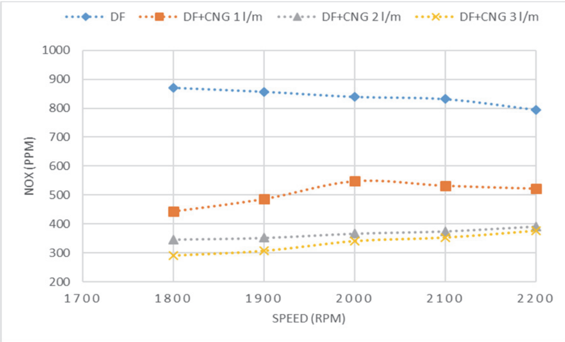

Figure 3: Effect of CNG addition and engine speed on NOx Emission.

4.2 Carbon Monoxide (CO)

Figure 4 present the effect of CNG addition and engine load on CO emission on diesel engine. According to Figure 4, when diesel engine operated normally, the CO emission generated from the combustion process is 445 ppm. The amount going down first, then increase when the engine load increase from 50% to 75% of engine load and keep increase during the increasing of engine load to 100%.

Opposite from diesel engine operation, on dual fuel operation, the increasing of CNG quantity on combustion chamber affect the increasing of CO emission. The increasing of CO emissions occurs between 400-600 times the amount of CO when operating in normal diesel. However, this amount gradually going down when the increasing of engine load. The lowest CO emission of dual fuel mode occurs when the engine operated on 75% engine load, and then slowly increase at 100% engine load. The amount of CO emission on normal diesel and dual fuel operated almost equal when engine operates at 100% engine load.

Natural gas air mixture ignited by diesel fuel as a pilot under dual fuel operation and the flames should spread through the charge. The mixture in some areas is too lean to maintain the propagation of fire. For this, the local temperature drops and the CO oxidation reaction freezes. This is the reason of CO emissions increase under dual fuel operation.

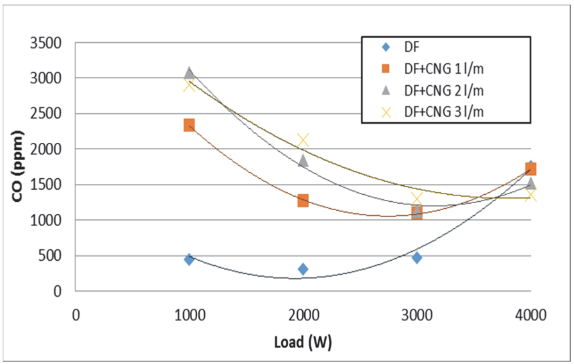

Figure 4: Effect of CNG addition and engine load on CO Emission.

4.3 Carbon Dioxide (CO2)

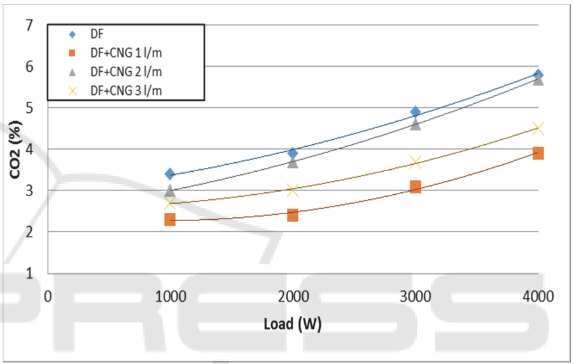

Figure 5: Effect of CNG addition and engine load on CO2 Emission.

The addition of CNG to the diesel engine combustion process affects the CO2 emissions produced by the engine as presented on Figure 5. When the engine operates in normal mode using diesel fuel, CO2 emissions generated from the combustion process are as much as 3.4%. However, the amount gradually decreases as the CGN is added to the combustion chamber. Under both engine operation, CO2 emission increase when the engine load increase. The reduction of CO2 in every engine load occur. The reduction of CO 2 emission at 25%, 50%, 75% and 100% engine load respectively are 11%, 5.1%, 6.1% and 3.3%.

CNG with the main constituent of methane gas has one of the lowest carbon content among hydrocarbons. CNG combustion has the potential to produce lower CO2 emissions compared to diesel. Under dual fuel mode, imperfect combustion is a serious problem. Some fuels are not fully oxidized to CO and dumped into the exhaust pipe, which can reduce CO2 emissions.

5 CONCLUSION

The effect of CNG addition has been investigated above. According to data obtained, the conclusion of this study are:

1. The NOx emission formed by high temperature of combustion process. The addition of CNG on dual fuel operation decrease the NOx emission. The most reduction of NOx emission obtained when engine operates at low load under dual fuel operation. In the other hand, the increasing of CNG quantity also affect the NOx reduction.
2. The CO emission formed because of incomplete combustion of engine. The addition of CNG on diesel operation affect the increasing of CO emission. Under normal diesel operation, the amount of CO going down firs and then increase when the engine load increase. However, under dual fuel operation the CO emission gradually going down when the increasing of engine load.
3. The CO2 emission formed because of complete combustion process. The addition of CNG on diesel operation reduce CO2 emission. Under both engine operation, CO2 emission increase when the engine load increase

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REFERENCES

Hussain J., Palaniradja K., Alagumurthi N., Manimaran R., 2012. Effect of Exhaust Gas Recirculation (EGR) on performance and emission characteristics of three cylinder direct injection compression ignition engine, *Alexandria Engineering Journal, 51, 241-247*.

C. P. Fenimore, 1971. Formation of nitric oxide in premixed hydrocarbon flames, *Symp. Combust. 13 (1) 373–380*.

Arif A., Sudarmanta B., 2015. Karakterisasi performa mesin diesel sistem dual fuel Solar-CNG tipe LPGI dengan pengaturan start of injection dan durasi injeksi CNG, Tesis Magister, *Institut Teknologi Sepuluh Nopember Surabaya*.

C. T. Bowman, 1979. Kinetics of pollutant formation and destruction in combustion, in: *N.A. Chigier (Ed.), Energy and Combustion Science (Student Edition One), pp. 33–45 (Pergamon)*.

D. I. G. Stiesch, 2003. Modeling Engine Spray and Combustion Processes: *Springer Berlin Heidelberg*.

Ehsan Md, Bhuiyan S, 2009. Dual fuel performance of small diesel for application with less frequent load variations, *International Journal of Mechanical and Mechatronics Engineering (IJMME), 9 (10), pp 30-39*.

Heywood J. B., 1998. Internal Combustion Engine Fundamental, *New York: McGraw - Hill Book Co*.

JFE Engineering, 2014. Dual Fuel Engine Gas Fuel Conversion Technology, *JFE Technical Report, 19*.

K. Hoekman, C. Robbins, 2012. Review of the effects of biodiesel on NOx emissions, Fuel Process. *Technol. 96 (0) 237–249*.

Komar I., Antonic R., Matic P., 2007. Selective Catalytic Reduction as secondary methode to remove NOx from diesel engine exhaust gas, *IFAC Proceedings, 40 (17) 305-309*.

Mehta R., Chauhan A.K., Patel J., Khatri M., Panchal D., 2015. A study on dual fuel engine: Opportunities for development of non polluting and efficient I.C. Engine, *International Journal of Engineering Science and Innovative Technology (IJESIT), 4 (2) 420-424*.

Ohashi I., 2015. Dual fuel marine engine (highly reliable environmentally friendly engine), *YANMAR Technical Review*.

S. Fernando, C. Hall, S. Jha, 2006. NOx reduction from biodiesel fuels, *Energy Fuel 20 (1) 376–382*.

Sahoo B. B., Sahoo N., Saha U.K., 2009. Effect of engine parameters and type of gaseous fuel on the performance of dual-fuel gas diesel engine – A critical review, *Renewable and Sustainable Energy Reviews, 13, pp 1151-1184*.

Semin and R.A Bakar., 2008. A technical review of compressed natural gas as an alternative fuel for internal combustion engines, *American Journal of Engineering and Applied Sciences, 1, 302-311*.

Semin, Bakar R.A., Ismail A.R., 2007. Air flow analysis of four stroke direct injection diesel engines based on air pressure input and L/D ratio, *Research Journal of Applied Science, 2 (11), pp 1135-1142 (2007)*.

Semin, Bakar R.A., Ismail A.R., 2009. Green engines development using CNG as an alternative fuel; A review. *American Journal of Environmental Science, 5 (3), 371-381*.

Semin, Bakar RA, 2013. Simulation and experimental method for the investigation of comressed natural gas engine performance, *International Review of Mechanical Engineering (IREME), 7 (7)*.

Semin, Gusti A.P., Octaviani N.S., Zaman M.B., 2016. Effect of new injector on the torue performance characteristics of gas engine, *International Journal of Applied Engineering Research, 11 (11) 7462-7466*.

Semin, Octaviani N.S., Gusti A.P., Zaman M.B., 2016. Power performance characteristics investigation of gas engine using new injector, *International Journal of Applied Engineering Research, 11 (11) 7462-7466*.

Sun L., Liu Y.F., Zeng K., Yang R., Hang Z.H., 2015. Combustion performance and stability of a dual fuel diesel natural gas engine, *Proc Inst. Mech Eng. D.J. Automob. Eng. 229 (2), 441-453*.

T. Kitamura, J. Senda, H. Fujimoto, 2002. Mechanism of smokeless diesel combustion with oxygenated fuels based on the dependence of the equivalence ratio and temperature on soot particle formation, *Int. J. Eng. Res. 3 (4) 223–248.*

Tesfa B., Mishra R., Zhang Q., Gu F., Ball A.D., 2013. Combustion and performance characteristics of CI engine running with biodiesel, *Energy, 51 (0), 101-115*.

Tiwari A., 2015. Converting a diesel engine to dual fuel engine using natural gas. *International Journal of Enrgy Science and Engineering, 1 (5), 163-169*.

Wang Z., Zhao Z., Wang D., Tan M., Han Y., Liu Z., Dou H., 2016. Impact of pilot diesel ignition mode on combustion and emissions characteristics of a diesel/natural gas dual fuel heavy-duty engine, *Fuel 167, 248-256*.

Wei L., P. G., 2016. A Review on Natural Gas/Diesel Dual Fuel Combustion, Emissions and Performance. *Fuel Processing, 142, 264-278*.

Zoltoski A., 2014. Investigation of combustion process in dual fuel diesel engine, *Journal of KONES Powertrain and Transport, 21 (2)303-309*.