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Study of Dual Fuel Engine as Environmentally Friendly Engine

Nilam S. Octaviani, Semin

Abstract**—**The diesel engine is an internal combustion engine that uses compressed air to combust. The diesel engines are widely used in the world because it has the most excellent combustion efficiency than other types of internal combustion engine. However, the exhaust emissions of it produce pollutants that are harmful to human health and the environment. Therefore, natural gas used as an alternative fuel using on compression ignition engine to respond those environment issues. This paper aims to discuss the comparison of the technical characteristics and exhaust gases emission from conventional diesel engine and dual fuel diesel engine. According to the study, the dual fuel engine applications have a lower compression pressure and has longer ignition delay compared with normal diesel mode. The engine power is decreased at dual fuel mode. However, the exhaust gases emission on dual fuel engine significantly reduce the nitrogen oxide (NOx), carbon dioxide (CO_2) and particular metter (PM) emissions.

Keywords**—**Diesel engine, dual fuel engine, emissions, technical characteristics.

I. Introduction

DIESEL engine is an internal combustion engine that uses compressed air to generate power. The diesel engine is a type of machine that is widely used in the world because it has the most excellent combustion efficiency than other types of internal combustion engines. Moreover, diesel engines also have high reliability with relatively low operating costs [1], [2]. In contast with the benefits, the diesel engine has the disadvantages that affect the environment and humans. The exhaust gas of diesel combustion process is the largest contributor of air pollution that are harmful to the environment and human health [1].

Generally, the diesel engines are used as ship prime mover, using conventional marine fuel (diesel fuel, heavy fuel) which produced exhaust gas in the form of nitrogen oxides (NOx), particular metter (PM), sulfur oxides (SOx), carbondioxide (CO_2), carbon monoxide (CO), unburn hydrocarbon (UHC) and so on [5]. The exhaust gas is dangerous because it causes air pollution that affect on environmental and human health.

To prevent pollution produced by ships, in 1997 the International Maritime Organization (IMO) issued MARPOL Annex VI as regulation to limit air pollution caused by ship's emissions, especially restrictions on emissions of NOx, SOx, CO_2 and PM. Fig. 1 describes the plan for reducing emissions of NOx, SOx, CO_2 and PM generated by ships by IMO until 2025 [4]. Energy Efficiency Design Index (EEDI) established since 2013, is planned can suppress the amount of CO_2 that can be causing the Greenhouse Effect.

To face the IMO standards set, a lot of technology has been developed to reduce emissions of a main engine, such as application of Selective Cathalityc Reduction (SCR), Exhaust Gas Recirculation (EGR), Water Scrubber, Emulsion and Gas Engine. According to Ohashi [4], of all emission reduction technologies that are evolving, the gas engine technology is most applicable technology for effectively reducing emissions of SOx, NOx, PM and CO_2 simultaneously. Unlike the case with other emission reduction technology applications which can only reduce certain types of exhaust emissions.

This is reinforced by research conducted by Siddiek and Elgohary [9], about the strategies that can be applied to the vessel to reduce exhaust gas emissions. Based on the comparison and case studies using vessels operating in the Red Sea, the cruise line is the Egyptian and Saudi Arabia, showed that the selective cathalityc reduction and the water scrubber are the best technology to reduce vessel emissions, but have a disadvantage in economic factors. While, the application of natural gas as alternative fuel in ship is very satisfying in terms of the environment and the economy.

This paper will discuss about natural gas and its application in diesel engines. The technical characteristics and exhaust gases emission comparison between conventional diesel engine and dual fuel diesel engine will also be given in this paper.

II. Natural Gas

A. Natural Gas Composition

Natural gas is a natural resource which serves as an alternative fuel today. The main component of natural gas is methane (CH_4) with the composition between 87 and 96% [1], [6] and the other componentsin small uantities are propane, n-butane, isobutane, n-penthane, isopenthane, hexane, carbondioxide, nitrogen, oxygen, and hydrogen. Table I shows the composition of natural gas content. The composition and components of natural gas sources depend on the geological conditions and the production process. This means that if natural gas production wells are different, then the composition of the natural gas produced is also different.

Wei and Geng [1] studied about the combustion, emissions and performance of dual fuel engine explain that the natural gas is an environmentally friendly alternative fuel, because it contains less carbon per unit of energy compared with fossil fuels. In addition, natural gas also produces less CO2 emissions in every single mile drive engine, thus reducing the

N.S.Octaviani is with the Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia (e-mail: nilamoctavia@gmail.com)
Semin was with the Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia (e-mail: semin@its.ac.id).

influence of the greenhouse effect caused by CO2 gas. However, according to Zoltowski [7], the natural gas would be difficult to apply in compression ignition engines for natural gas is a type of fuel with a low cetane number but high in octane number. Cetane number is a fuel parameter that indicates the ability to "self-ignition". The higher cetane number of fuel it will be easier for these fuels to ‘self ignite’, for example a diesel fuel. Therefore, application of gas fuel in diesel engines is still in the research and development.

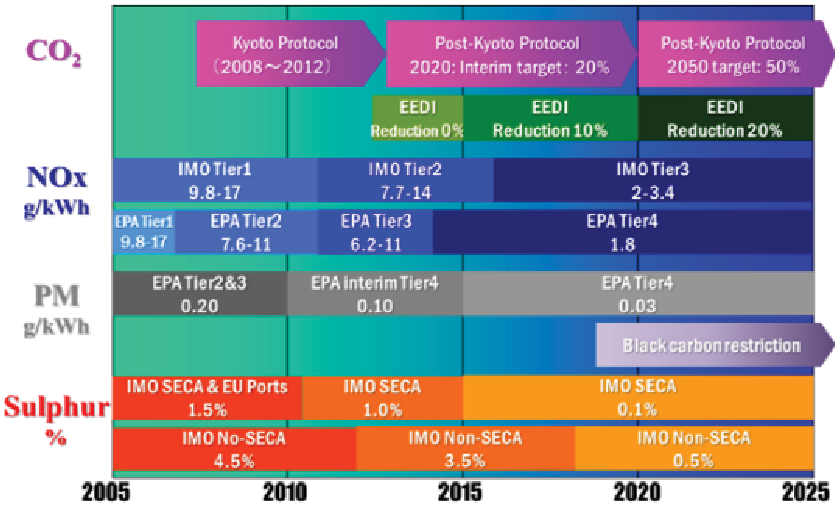

Fig. 1 Schedule of emissions and greenhouse gases reduction on ships by IMO [4]

TABLE I
NATURAL GAS COMPOSITION [1]

Component	Typical Analysis (vol%)	Range (vol%)
Methane	94.9	87-96
Ethane	2.5	1.8-5.1
Propane	0.2	0.1-1.5
Isobutane	0.03	0.01-0.3
n-Butane	0.03	0.01-0.3
Isopentane	0.01	Trace to 0.14
n-Pentane	0.01	Trace to 0.14
Hexane	0.01	Trace to 0.06
Nitrogen	1.6	1.3-5.6
Carbondioxide	0.7	0.1-1.0
Oxygen	0.02	0.01-0.1
Hydrogen	Trace	Trace to 0.02

B. Natural Gas Application Engine

Wei and Geng [1] classify the use of gas fuel in diesel engines into three, based on the process of gas reinjection into the combustion chamber and how the combustion process occurs. They are:

1.Conventional Dual Fuel

In this type of dual fuel engine, there are two injectors they are gas injector system which is located on the air inlet pipe, and a diesel injector which serves as a pilot fuel. When the intake valve opens, the gas is injected into the combustion chamber together with air. It is causing the initial mixing between air and gas fuel. Combustion will occur when the pilot fuel with a high cetane number is injected into the combustion chamber at the end of the compression stroke [3], [8]. Schematic diagram is presented in Fig. 2.

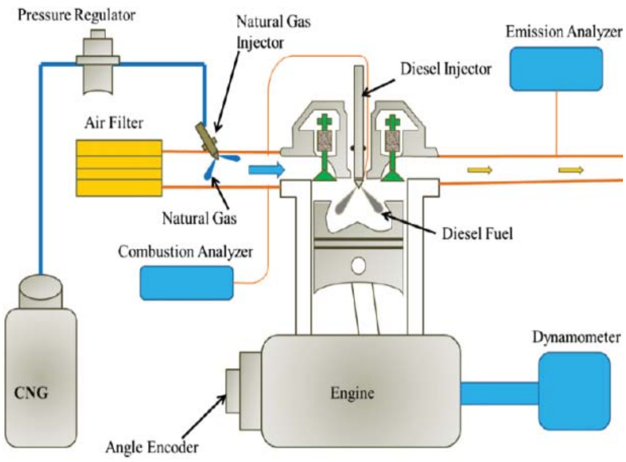

Fig. 2 Schematic diagram of conventional dual fuel using CNG [15]

2.High Pressure Direct Injection (HPDI)

In this type of engine, there is an injector that serves to deliver gas and diesel fuel into the combustion chamber. Diesel fuel serves as a pilot fuel is injected first into the combustion chamber at the end of the compression stroke, reinjection serves to cause a spark. Furthermore, shortly thereafter, the gas is injected directly into the combustion chamber and burned so that the combustion process occurs [10]-[12]. Schematic diagram is presented in Fig. 3.

3.Hot Surface Assisted Compression Ignition

In this type of machine, there is only one injector that injects natural gas directly into the combustion chamber. Gas is injected near the surface of the heat at the end of the compression stroke [13]. Hot surfaces usually a glow plug with a temperature between 1200-1400K [14]. Gas through the hot surface will produce sparks so that the combustion process occurs. This type of engine main forte is the high specific power and thermal efficiency of combustion knock without limitation. Schematic diagram is presented in Fig. 4.

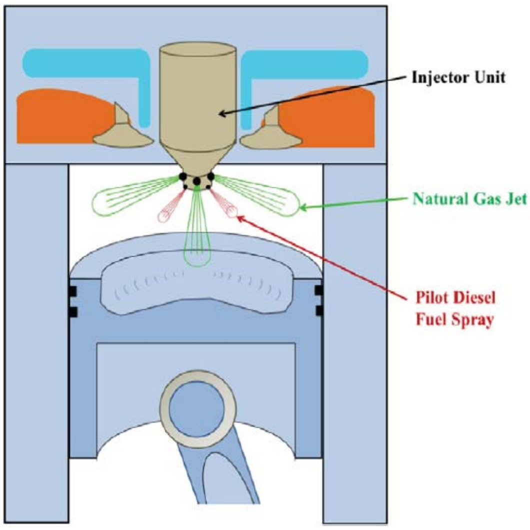

Fig. 3 Schematic diagram of high-pressure direct injection system [1]

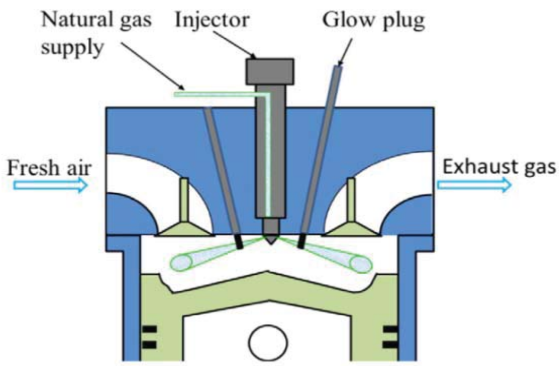

Fig. 4 Schematic diagram of hot surface assisted compression ignition [1]

III. Dual Fuel Concept

Dual fuel diesel engine is a development of the diesel engine that uses two types of fuel to burn. The principle of a dual fuel engine is a combination of the working principle of compression ignition engines and spark ignition engines [3]. Compression ignition engines (diesel engines) work with pressurized air relying on pressure and temperature to produce when burning fuel with a high cetane number is injected fuel space. While in spark ignition engines (otto engines), fuel with a high octane number first mixed in the carburetor, and then the mixture of fuel and air pressure below its ignition point and then burned with the aid of the spark plug.

In dual fuel engines, gas and air goes into the combustion chamber simultaneously and undergo initial mixing. The mixture of gas and combustion air does not ignite because gas has a high-octane number. This is similar to the working principle of spark ignition engines. Furthermore, the mixture of fuel and the gas is compressed, and at the end of the compression stroke so that the injected pilot fuel combustion occurs. This process is similar to the working principle of compression ignition engine.

IV. Combustion Process

The combustion process on diesel conventional engine can be devided into four stages, as presented in Fig. 5. They are A-B; period of ignition delay, B-C; premixed combustion (rapid pressure rise), C-D; normal combustion and D-E; late combustion. Point A is the start of diesel fuel injection and point B is the start of combustion process.

Combustion process on dual fuel directly injection engine can be devided into five stages, as shown in Fig. 6. They are pilot fuel ignition delay (AB), pilot premixed combustion (BC), gas fuel ignition delay (CD), rapid combustion of gas fuel (DE), and the diffusion combustion stage (EF). Point A is the injection of pilot fuel begin, point B is combustion of pilot fuel begin, point C is the injection of primary fuel begin and point D is the combustion of primary fuel begin.

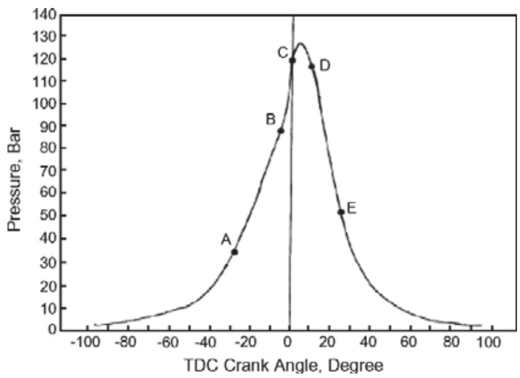

Fig. 5 Combustion process of conventional diesel engine [16]

According to Fig. 6, Sahoo et al [3] explained that the ignition delay of pilot fuel in dual fuel operation (AB) was longer than pure diesel fuel in conventional diesel engine operation. It was influenced by the reduction of oxygen levels in combustion process resulting from the substitution of gas fuel for air. The pressure rise of dual fuel operation (BC) was quite low as compared to conventional diesel operation due to the ignition of small quantity of pilot fuel. The period of the gas ignition delay occurs very short compared to the period of the pilot fuel ignition delay, its affected by the injection of pilot fuel first in the combustion chamber. When the gas began injected into combustion chamber, the pressure decreases slowly (CD) to the actual combustion of gases fumigated begins. The phase of gas combustion (DE) is unstable because it begins with the propagation of fire that has been generated from the combustion of the pilot fuel. The pressure rise does not cause any operating problems due to modest improvement occurred in the volume of the cylinder. Diffusion combustion stage (EF) started at the end of a rapid pressure rise and continued until the expansion stroke. This is caused by the slower of combustion rate of gaseous fuel and the presence of diluents from the pilot fuel. The combustion gas-air mixture can't occur completely at this stage due to low oxygen concentration, valve overlap, flame quenching on the walls or the effects of cracks. The success of this phase primarily depends on the length of ignition delay.

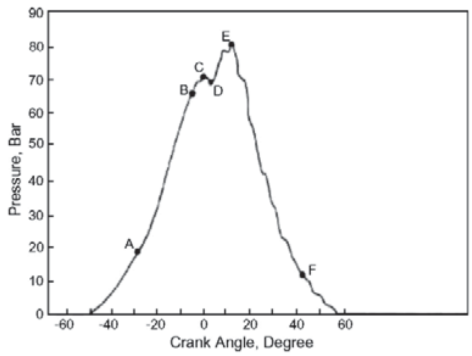

Fig. 6 Combustion process of dual fuel direct injection engine [16]

Wei and Geng [1] reviewed the performance characteristics of the conventional diesel mode and the natural gas/diesel dual fuel mode. It has been found that dual fuel mode has a longer ignition delay and lower compression pressure compared with normal diesel mode. The engine power is decreased up to 2.1% when operated on dual fuel mode, but the power loss can be recovered by changing some of the operating parameters, such as number of nozzel, nozzel size, fuel injection pressure and so on. The brake thermal efficiency (BTE) on dual fuel engine is lower in the low and medium loads, while under high engine load it is similar or slightly higher when compared with conventional diesel mode. The maximum increase was about 3% on the engine under full load condition. The variation coefficients indicated mean effective pressure seems to be higher in dual fuel mode and decreased with the increasing of engine load.

Zoltowski [7] experimentally investigated the combustion process in dual fuel diesel engine four cylinders, 85 kW. He concluded that the increase of methane content in fuel causes proportional increase of ignition lag and delay in heat release process. However, the increase of methane concentration factor in fuel combustion causes the maximum cylinder pressure is getting smaller. The efficiency of dual fuel engine also decreases with the increase of methane content in fuel. Therefore, to compensate influence the combustion delay the injection advance should be adjusted.

Zhang, Li and Shao [11] analyzed the combustion process of a heavy-duty engine fueled with directly injected natural gas and pilot diesel. The experiments were carried out under to operating points, they are A; 1275 rpm, 1.05 Mpa and B; 1550 rpm, 1.05Mpa with diesel fuel injection pressure varied between 18-30 MPa and the start of natural gas injection in the range of 1°BTDC to 19°BTDC. When engine operating at the higher engine speed of 1550 rpm, the maximum cylinder pressure reaches lower value with delayed occurrence compared with that of lower speed of 1275 rpm. The maximum heat release rate increases and takes place earlier with higher injection pressure and lower engine speed. The flame development duration shows a generally decreasing trend with advancing injection timing. Moreover, raising injection pressure and decreasing engine speed also reduce the flame development duration. The effects of operating conditions on rapid combustion duration, however, seem to be uncertain, exhibiting different tendencies at different injection pressure.

V. EMISSION

Wei and Geng [1] reviewed the emissions characteristics of the conventional diesel mode and the natural gas/diesel dual fuel mode. The dual fuel mode could significantly decrease the NOx, CO_2 and PM emissions, but the HC and CO emissions may increase by several times or even more than 100 times. NOX emission under dual fuel mode was affected by engine loads and pilot diesel quantity; it may increase at high engine load. With the increase of engine load and pilot diesel quantity and the advance of pilot diesel injection timing, HC emission under dual fuel mode will decreases but NOX emission increases. There was a trade-off relationship between NOX and HC emissions during dual fuel combustion. While with the increase of natural gas, CO emission shows a decreasing trend after the first increase.

Zoltowski [7] experimentally investigated the emissions characteristics in dual fuel diesel engine four cylinders, 85 kW. It can be concluded that with the increasing of methane concentration in the fuel cause NOx, non-methane hydrocarbons (NMHC) and CO_2 emissions have decreased. However, emissions of CO and total hydrocarbons (THC) increased. The changes of NOx emissions generally influenced by two factors. They are the air-fuel ratio (oxygen availability) and the temperature at which nitrogen oxidation reaction took place. The greatest impact on emissions of CO was observed. Extra 50% methane content in the fuel additives increase CO emissions of 0.5 g / kWh to 12 g / kWh. The increasing emissions of CO occur more than 20 times.

Zhang, Li and Shao [11] also analyzed the emission of a heavy-duty engine fueled with directly injected natural gas and pilot diesel. When operating at higher engine speed of 1550 rpm, THC emissions can be improved by advancing injection timing, while at lower engine speed of 1275 rpm, reducing the injection pressure would be more effective. CO emissions show a first increase and then decrease trend with injection timing while get worse with lower engine speed, however, the changing trend with injection pressure is inconsistent at different engine speed. NOx emissions suffer from advanced injection timing, higher injection pressure as well as lower engine speed, all of which, on the contrary, have positive effects on fuel economy.

VI. CONCLUSION

Along with the increasing environmental issues, the use of natural gas as an alternative fuel is very promising to be applied to dual fuel diesel engines, because it significantly reduce the emissions particularly restriction on NOx, CO_2 and PM emissions, although the emission of CO and total hydrocarbons (THC) increased. However, dual fuel engine applications still need a lot of attention by doing research related to the development of dual fuel engine. Because the dual fuel engine has a lower compression pressure compared with normal diesel mode. The ignition delay of dual fuel mode is longer than normal diesel mode. The power is also decrease when engine operated under dual fuel mode. However, the power loss of dual fuel engine can be recovered by adding or changing some of the operating parameters specially with advancing the injection timing.

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Nilam S. Octaviani was born at Bengkulu, October 31st 1993. Currently, the author pursuing a doctoral program at Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

She has published a paper in the International Journal of Applied Engineering Research (IJAER) on May 2016. The publication was: Semin, Nilam S. Octaviani, Ayudhia P. Gusti, M. Badrus Zaman, Power performance characteristics investigation of gas engine using new injector, *International Journal of Applied Engineering Research*; 2016; Vol 11 (11); 7462-7466. She also has performed in international conferences (SENTA 2016) as presenter. The International Conference was held in Surabaya, Indonesia on December 2016. The publication as: Nilam S. Octaviani, Semin, M.L.P Putra, I M. Ariana, Economical overview of homogenizer installation on ship fuel system, SENTA; 2016.

Semin was born at Surabaya, January 10th 1971. Completed the bachelor degree in 1996 and master degree in 2002 at Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. Tthe doctoral program has completed in 2011 at the Universitu Malaysia Pahang.

He has published a paper in the International Journal of Applied Engineering Research (IJAER) on May 2016. The publication was: Semin, Nilam S. Octaviani, Ayudhia P. Gusti, M. Badrus Zaman, Power performance characteristics investigation of gas engine using new injector, *International Journal of Applied Engineering Research*; 2016; Vol 11 (11); 7462-7466. He also has published a paper in the International Journal of Applied Engineering Research (IJAER) on 2015. The publication was: Semin. 2015. Analysis of Biogas as an Alternative Fuel for Electric Generator Engine in Bawean Island – Indonesia. International Journal of Applied Engineering Research 10 (16). pp. 35313-35317 and Semin. 2015. Investigation the Effect of Injector Nozzle Multi Holes Geometry on Fuel Spray Distribution Flow of CNG Engine Based on Computational Modeling. International Journal of Applied Engineering Research 10 (15). pp.36087-36095.

Prof. Semin scientifict associations membership from 2004 till present are IMARE (Institute of Marine Engineer, Indonesia) (Membership since 2004), RINA (Royal Institute of Naval Architecture, UK) (Membership since 2004), American Society of Mechanical Engineer, USA (Membership since 2006), Index Copernicus Scientists (Membership since 2007), IAENG (International Association of Engineer), Hong Kong (Membership since 2008), IMarEST (Institute of Marine Engineering Science and Technology, UK) (Membership since 2011).