Effect of Combustion Design for Diesel Dual Fuel Engine
(Effect of Using GTL Diesel Fuel for DDF Engine)

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Abstract

A feasibility study was conducted on reducing total hydro carbon (THC) emission for diesel dual fuel (DDF) engine by using gas to liquids (GTL) diesel fuel from combustion design perspective. Natural gas is expected as the fuel reducing carbon dioxide (CO_2), and furthermore Shale gas is expected to supply more inexpensively [1]. However, natural gas engines generally use Otto cycle, therefore thermal efficiency is lower than the diesel engine, and then the brake specific fuel consumption (BSFC) becomes worse. Thus, DDF engine using a Diesel cycle is invented in order to improve the BSFC of natural gas engine. However, DDF engine still has THC emission issue. The other hand, GTL is expected as possible alternative fuels produced from variety raw materials. GTL is known as high ignitability. Consequently, this study was made on improving ignition and reducing THC emission of DDF engine by using GTL. The test engine was fabricated by a modified conventional diesel engine. The gas mixer was set on the intake pipe of general diesel engine in order to suck natural gas from the intake manifold. The engine can suck premixed gas of air and natural gas. This premixed gas is ignited by the fuel injection after compression. Test engine is investigated that it can operate stable operation successful DDF combustion of GTL diesel fuel. Although BSFC get worse at low load, BSFC of high load is found to be better than the diesel combustion. In Addition, nitrogen oxides (NO_X) emission increases at the highest load. However, the area satisfying both low NO_X and low BSFC is confirmed. Moreover, particulate matter (PM) in the exhaust gas is confirmed to be reduced dramatically.

Keywords: gas to liquids, natural gas engine, diesel dual fuel engine, combustion design

1 Introduction

The natural gas is expected as feasibility alternative fuel, since it can reduce carbon dioxide (CO_2) in the exhaust gas. In addition, Shale gas is anticipated stability of supply because it reserves abundance. From this reason, natural gas will be more important for environmental problem in the future.

However, natural gas engines generally use Otto cycle which is ignited by the spark plug because natural gas has low self-ignitability. Therefore, thermal efficiency is lower than the diesel engine. Besides, the brake specific fuel consumption (BSFC) becomes worse. Thus, Diesel Dual Fuel (DDF) engine which using a Diesel cycle is invented in order to improve the BSFC of natural gas engine. DDF engine sucks mixture of air and natural gas. Then this mixture is ignited by the fuel injection after compression. Therefore, DDF engine can be operated with a Diesel cycle, and then it can make high efficiency. Consequently, DDF engine is anticipated as an engine that can improve the fuel consumption of the natural gas engine [1], and furthermore it can reduce CO_2 emission.

On the other hand, Gas to Liquids (GTL) fuel is expected as possible alternative fuel produced from variety raw materials. For example, it can be produced from biomass, coal and natural gas. Particularly, it is told that GTL which is produced from natural gas has good ignitability [2]. Therefore, GTL is focused on ignition fuel for DDF engine. Consequently, this study was made on improving ignition and reducing total hydro carbon (THC) emission of DDF engine by using GTL from combustion design perspective. This paper describes the influence of combustion design for DDF engine.

2 Properties of test fuels

In this study, the properties of test fuels were investigated before the engine performance test in order to confirm the difference of characteristics. Therefore, gas oil (JIS #2) was measured for the reference.

Figure 1 gives the measured density and kinematic viscosity of test fuels. Density was measured by the float test, and viscosity was measured by using the viscometer (A&D; VM-10A-L). Besides, Table 1 shows difference of the properties comparing GTL and gas oil.

From this figure, density and kinematic viscosity of GTL were confirmed to be the same with gas oil. If density and kinematic viscosity are different the fuel spray characteristics will be change. If the density or kinematic viscosity is higher, fuel spray will run long distance. Then fuel spray hits the cylinder wall, and the fuel cannot burn because of cool wall. In other words, time to vaporization is longer. Therefore, the ignition delay period becomes longer, it affects the exhaust emissions and cylinder pressure. On the contrary, if the density or kinematic viscosity is lower, fuel spray will stay near the injector; this means fuel spray will stay center of combustion chamber. Then, fuel leads to incomplete combustion. Furthermore, diesel engines are needed the enough lubrication with the fuels for the fuel pump and injector. This similar kinematic viscosity makes good lubrication inside of them, and it will not be broken them with respect to kinematic viscosity.

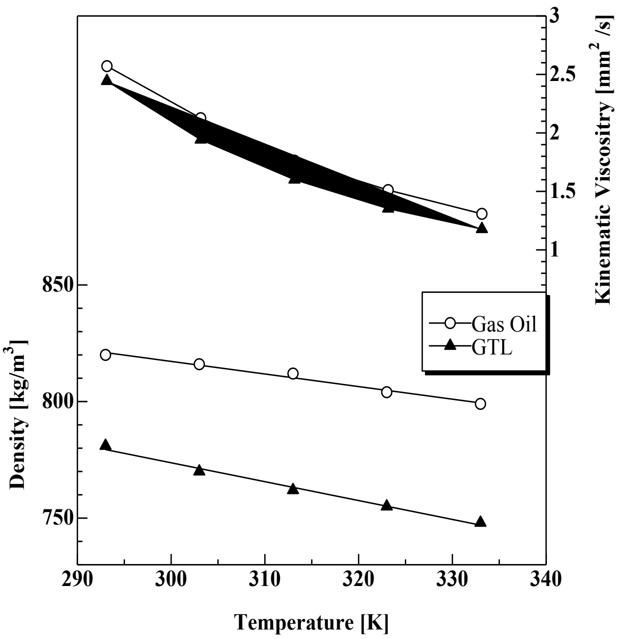

Fig. 1 Density and kinematic viscosity

Table 1 Properties of gas oil and GTL

	Gas Oil (JIS#2)	GTL
Density [kg/m³(@303K)]	806	765
Kinematic Viscosity [mm²/s(@303K)]	2.1	1.9
Flash Point [K]	340.2	369.5
Lower Calorific Value [KJ/kg]	43000	43500
Pour Point [K]	255.7	270.5
C[%]	87.2	84.9
H[%]	12.8	15.1
Cetane Number	59.9	78.4
Cloud Point [K]	-	272
HFRR [µm]	440	410

Table 1 presents properties comparing GTL and gas oil. There are some differences, in particular the cetane number of GTL is higher than gas oil. Therefore, it can improve the ignitability of natural gas by using GTL [3]. In addition, CO_2 emission of GTL will be lower than gas oil because C/H ratio is lower than that of gas oil. Moreover, GTL has good HFRR. Consequently, GTL can be considered make good engine performance.

3 Engine performance test

3.1 Experimental apparatus and method

The engine performance test was carried out in order to declare the influence of GTL for DDF combustion and exhaust emission characteristics. **Figure 2** presents the engine performance test apparatus. The engine used in this study was produced by improving conventional water-cooled single cylinder direct injection diesel engine. A gas mixer was set on the intake pipe in order to charge natural gas. This engine can suck mixture of air and natural gas. Then this mixture is ignited by the fuel injection after compression. GTL is used this fuel injection. The base engine specifications are shown in **Table 2**. Then, the experiment was performed under the following conditions:

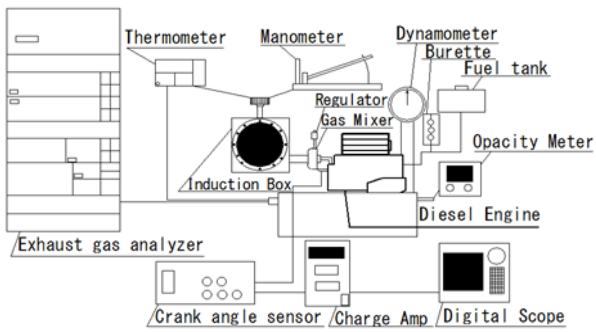

Fig. 2 Experimental apparatus

Table 2 Engine specifications

Model	YANMAR NF19-E
Displacement Volume [cc]	1007
Bore × Stroke [mm]	110×106
Compression Ratio	16.3
Maximum Output [kW/rpm]	14/2400
Rated Output [kW/rpm]	12/2200
Injection Pressure [MPa]	19.6
Fuel Injection Timing	BTDC19°±1°
Combustion Chamber	Direct Injection

Diesel operation was set five step loads by the dynamometer. These loads were selected up to the continuous horse power of the test engine. In addition, DDF operation was set six step loads for over load because DDF can operate with less PM. DDF operation and diesel operation have same drive conditions such as same fuel injection timing or same fuel injection pressure. There is only difference on the suction air which contains the natural gas or only air.

The pressure and temperature also the amount of intake air, cylinder pressure and crank angle, exhaust gas temperature, they were measured and recorded with the data logger. Exhaust gas was sampled directly from the exhaust pipe in order to measure the particulate matter (PM) precisely by the opacity meter (HORIBA; MEXA-600SW). Also, exhaust emissions such as oxygen (O_2), carbon monoxide (CO), CO_2, THC and nitrogen oxides (NOx) were precisely measured from directly sampled exhaust gas by using the exhaust gas analyzer (HORIBA; MEXA-9100D). In addition, engine performance such as BSFC was investigated. Finally, combustion of each fuels were analyzed from recorded cylinder pressure and crank angle.

3.2 Results and discussions

Figure 3 gives the engine performance test results of each fuel. The shaft horse power is set on horizontal axis, exhaust emissions and BSFC are on vertical axes in this figure. In addition, the cylinder pressure and heat release rate at the highest load are shown in **Fig. 4**.

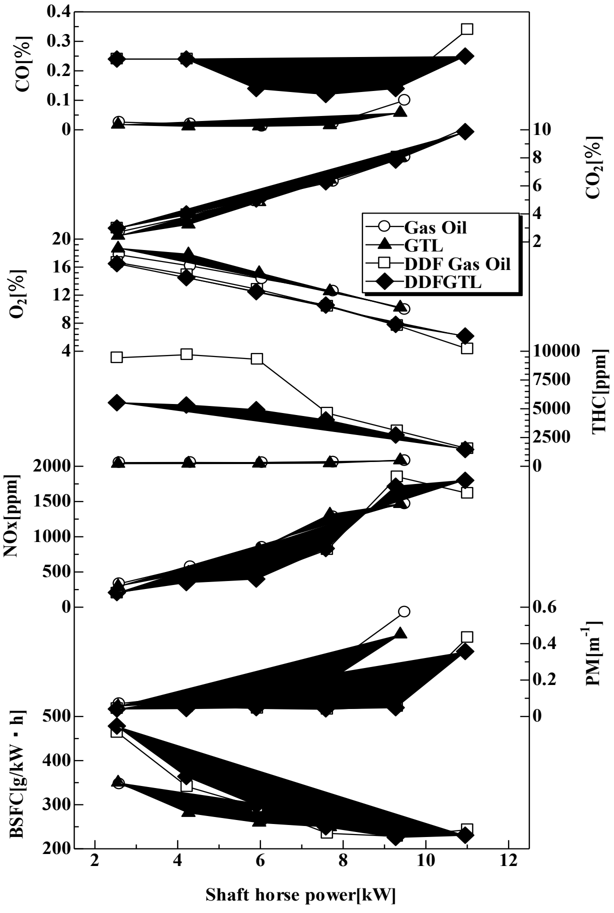

Fig. 3 Engine performance test results

From **Fig. 3**, PM emissions of both DDF can be confirmed to be reduced significantly from diesel combustion. This is considered that reduction of diffusion combustion period by two-stage premixed combustion of natural gas and liquid fuel. From Fig. 4, it can be found that both DDF is reduced the diffusion combustion period of near 15 ~ 25 [° CA]. This is considered that the diffusion combustion period of the liquid fuel is reduced by increasing premixed combustion of natural gas [4]. Therefore, PM emission is reduced by increasing premixed combustion. Furthermore, PM emission of DDF is slightly reduced by GTL [5]. This is considered due to the high cetane number of GTL. Also, natural gas is difficult to form a PM. Consequently, PM is reduced significantly by DDF combustion [6].

Nitrogen oxides (NOx) emissions of both DDF are increased in the higher load. This is considered multi-point simultaneous ignition has occurred before the flame propagation from liquid fuel. Then, the combustion temperature is increased, and then NO_X emission is increased. Also, from **Figure 4**, it can be seen that cylinder pressure of both DDF is rising. This is considered due to the influence of high cetane number of GTL. However, NOx emission is reduced lower than diesel operation at low and medium loads. This area is supplied a small amount of liquid fuel. Therefore, NO_X reduction can be considered that the combustion temperature is restrained lower, since premixture is homogenized.

Carbon dioxide (CO_2) was expected lower because the main component of natural gas is methane which has low C/H ratio. However, both DDF operation emits CO_2 same amount that of diesel operation. This cause is

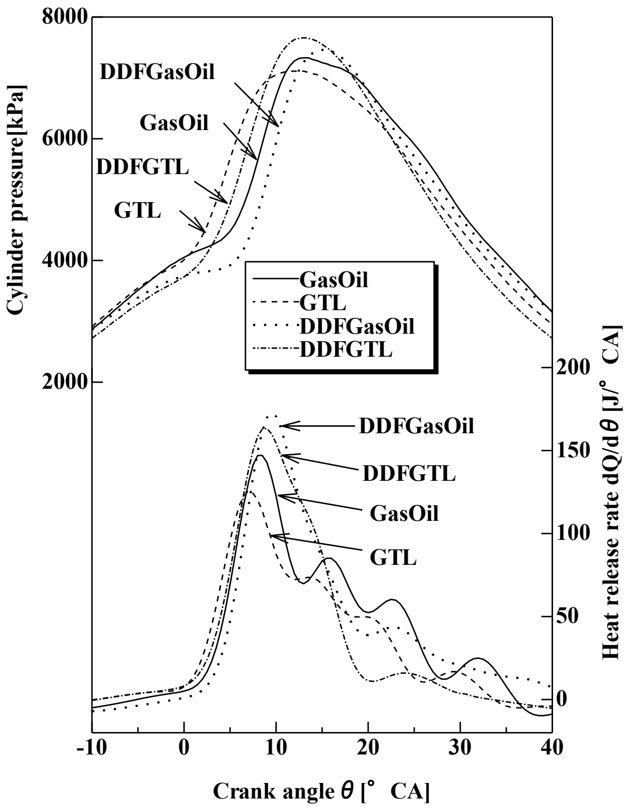

Fig. 4 Cylinder pressure and heat release rate at the highest load

consider the difference between the engine our and the tail pipe out. This CO_2 is the value of the engine out. The tail pipe out CO_2 will be increased because exhaust gas is oxidized by the Diesel Particulate Filter (DPF) and catalyst. However, both DDF operations reduces PM emission significantly, according to this reduced PM will make little CO_2 emission with DDF operation, in reverse PM of diesel operation will make much CO_2 because diesel operation emits much PM. Consequently, it can be said that DDF combustion reduces CO_2 emission.

THC of both DDF operations is quite higher than that of diesel operation at low load. This can be consider that natural gas is not burned at low load, since injected liquid fuel is little. However, DDF is improved lower by using GTL. It can be said that high cetane GTL can improve THC issue of DDF engine; this is to say that GTL has possibility for DDF engine.

BSFC of both DDF operations is found to be superior to diesel operation in the high load area. NO_X is also increased in the high-load. However, it is found the area that can achieve both low BSFC and low NO_X. If this DDF engine is used for a generator, it can be operated only at specific load. The DDF engine is possibility to be used as the generator.

Thus, combustion design using high ignitability GTL can change DDF combustion and emissions. It can be said that combustion design based on ignitability can reduce THC. Furthermore, DDF GTL has possibility of CO_2 reduction.

4 Conclusions

In this paper, the experimental study was made on improving exhaust emissions and combustion by using the GTL from the point of view of combustion design. The fuel properties were measured before the engine performance test. Then, natural gas and GTL were burned in a DDF engine in order to declare the influence of them. The main conclusions can be summarized as follows:

1) GTL has similar fuel properties with gas oil, though cetane number is higher than gas oil.
2) PM emissions of DDF is confirmed to be reduced significantly from diesel combustion.
3) NO_X emissions of DDF is increased in high load, but low-medium load is slightly lower than diesel operation by lean combustion of natural gas.
4) CO_2 emission of DDF is equivalent to diesel operation. However, CO_2 emission of tail pipe out can be considered significantly reduced.
5) THC emissions showed a high value in both DDF. However, DDFGTL is confirmed reduction effect due to the high cetane number of GTL.
6) BSFC of DDF engine can be improved by using GTL from the combustion design viewpoint.

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