Development of LNG dual fuel technology to reduce CO_2

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Abstract

This paper explains dual fuel technology to reduce CO_2 in terms of engine control parameters, intake manifold configuration and catalyst efficiency. Dual fuel engine was equipped with oxidation catalyst to meet EURO-3 regulations.

Experimental results showed that diesel injection timing and alternative ratio had a great effect on catalyst efficiency and CO_2 emission. Effect of diesel injection timing and alternative ratio had a significant difference between high and low load.

Also, intake manifold configuration was greatly related to air mass flow and combustion condition due to the volumetric efficiency.

Both THC and CO emissions were greatly reduced through application of oxidation catalyst. Additionally, the optimized P_d/P_t ratio was evaluated in terms of fuel consumption, reduction of harmful emission and cost.

1. Introduction

Natural gas, which is predominately methane, has been considered as a viable alternative fuel in terms of stability, economic feasibility, safety and cleanness. Methane offers useful physical-chemical properties such as wide flammability range, the capability of forming homogeneous air-fuel mixture and anti-knocking property. Also, supply of natural gas is stable because it is widely distributed throughout the world and its deposit is about 150 trillion m^3. Furthermore, natural gas is superior to existing hydrocarbon-based fuel in safety aspect due to a fast diffusion and high octane number.

The compression ratio of most conventional diesel engines can be maintained due to the high auto-ignition temperature of natural gas in case of the conversion of diesel into dual fuel engine.[1)] Moreover, dual fuel engine can effectively reduce CO_2 because C/H ratio of natural gas is greatly lower than existing hydrocarbon-based fuel.

This paper describes converted diesel engine to run on a mixture of natural gas and diesel. In this dual fuel system, natural gas is the primary fuel and a diesel pilot is used as the ignition source. Especially, this paper explains dual fuel technology to reduce CO_2 in terms of engine control parameters, intake manifold configuration and catalyst efficiency. Also, it is necessary to use an oxidation catalyst in exhaust system to reduce THC and CO to an acceptable level. EURO 3 regulations is applied to D6CB 380ps engine tested in this experiment. Additionally, the optimized control range is evaluated in terms of fuel consumption, reduction of harmful emission and cost.

2. Experimental apparatus

Fig. 1 Dual fuel engine

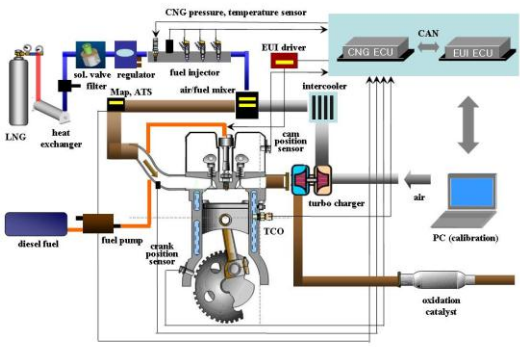

Fig. 2 Schematic of dual fuel system

D6CB engine, which is manufactured by HYUNDAI corporation, is operated by EUI (Electronic Unit Injector) and the compression ratio is maintained in case of the conversion of diesel into dual fuel engine.

Table 1. Specification of test engine

Engine	D6CB Diesel engine	Retrofit engine
Max power[ps] / rpm	380/1900	380/1900
Max torque[kg.m] / rpm	160/1200	160/1200
Type	In-line 6	←
Aspiration	TCI	←
Displacement volume [cc]	12, 344	←
Bore × Stroke [mm]	130 × 155	←
Compression ratio	17	←
Fuel supply system	Diesel EUI	Diesel EUI / LNG TBI
Ignition	Compression ignition	←

As shown in the figure 2, natural gas is the primary fuel and a diesel pilot is used as the ignition source in dual fuel system. Natural gas is converted a liquid form into a gas form through heat exchanger and is supplied to engine by means of mixer. Especially, diesel injection timing is a significant factor in dual fuel system because it has a great effect on thermal efficiency, alternative ratio, knocking and emission level. Also, dual fuel engine can meet EURO 3 regulations through oxidation catalyst.

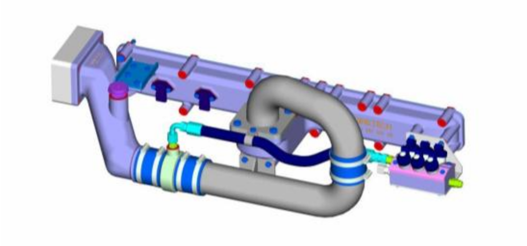

Fig. 3 Configuration of 1st retrofitted intake manifold

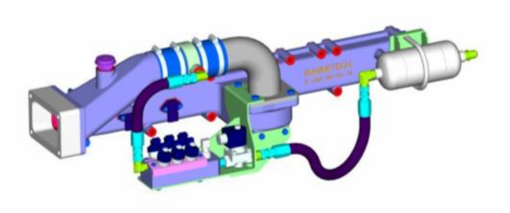

Fig. 4 Configuration of 2nd retrofitted intake manifold

Figure 3-4 present intake manifold applied to dual fuel engine. Intake manifold configuration has a direct effect on combustion stability, distribution, homogeneity and the volumetric efficiency because natural gas is supplied by mixer method. This paper evaluates variation of air mass flow and CO_2 concentration for intake manifold configuration.

Also, this paper estimates conversion ratio of catalyst through changing Pd/Pt ratio.

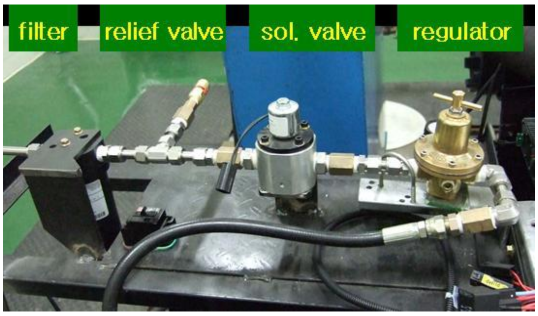

Fig. 5 LNG supply parts

Fig. 6 Oxidation catalyst of dual fuel engine

Table 2. Specification of LNG supply parts

Parts	Specification
LNG tank	P_{max}: 16 bar
Filter	P_{max}: 800 bar
Relief valve	24.1 bar
Sol. valve	C_v: 5.0, K_v: 4.31
Regulator	P_{out}: 50 ~ 120 psi
Oxidation catalyst	L_1 P_d/P_t, L_2 P_d/P_t, L_3 P_d/P_t ($L_1 > L_2 > L_3$)

3. Result

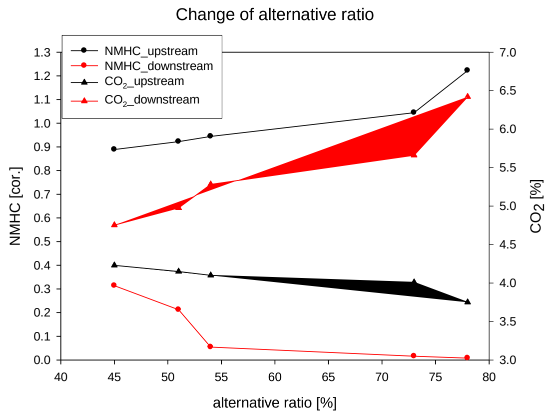

Fig. 7 Variation of harmful emissions for change of alternative ratio; 1600rpm, 25% load

Figure 7 shows variation of harmful emission between upstream and downstream of catalyst under low load according to changing alternative ratio. Alternative ratio is a significant parameter to improve thermal efficiency and fuel consumption and has a remarkable effect on catalyst efficiency under low load. The more alternative ratio increases, the more NMHC emits due to bulk quenching and quench layer[2,3] caused by slow burning speed in upstream of catalyst under low load. Also, CO_2 is reduced due to decrease of the average C/H ratio according to increasing alternative ratio.[4,5]

On the other hand, tendency of harmful emissions in downstream of catalyst becomes reverse compared to its tendency in upstream of catalyst. CO_2 increases relatively due to activity of oxidation catalyst for a great quantity of NMHC according to increasing alternative ratio. Difference of emission tendency between upstream and downstream of catalyst is caused by a sensitive response of catalyst efficiency for light off temperature under low load. Also, CO_2 greatly decreases according to decreasing alternative ratio in downstream of catalyst but NMHC rapidly increases in less than 50% and total cost of fuel rises too. Therefore, alternative ratio has to be varied in view of both catalyst efficiency and total economic feasibility.

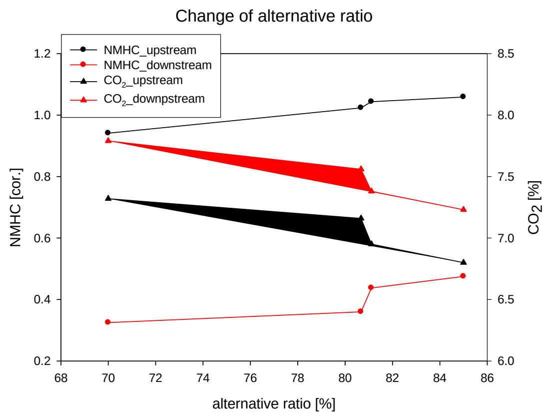

Fig. 8 Variation of harmful emissions for change of alternative ratio; 1600rpm, full load

Figure 8 shows variation of harmful emission between upstream and downstream of catalyst under high load according to changing alternative ratio. The more alternative ratio increases, the more NMHC emits due to bulk quenching and quench layer caused by slow burning speed in upstream of catalyst under high load. Also, CO_2 is reduced due to decrease of the average C/H ratio according to increasing alternative ratio increases. On

the other hand, tendency of harmful emissions in downstream of catalyst becomes similar compared to its tendency in upstream of catalyst. Oxidation catalyst isn't sensitively influenced by light off temperature due to relatively high exhaust gas temperature under full load.

In addition, alternative ratio under high load has to be varied in terms of max exhaust gas temperature, knocking and thermal efficiency.

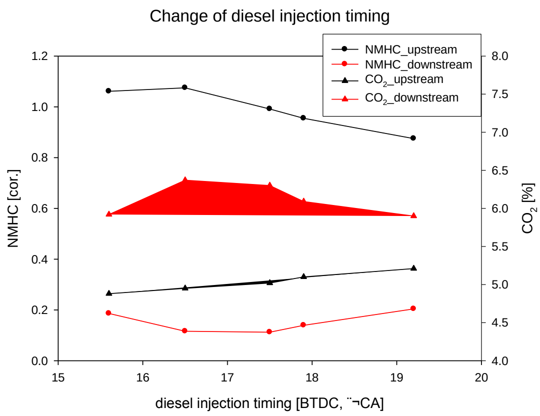

Fig. 9 Variation of harmful emissions for change of diesel injection timing; 1600rpm, 50% load

Figure 9-10 show variation of harmful emission and exhaust gas temperature between upstream and downstream of catalyst according to changing diesel injection timing. Diesel injection timing is the most important factor in dual fuel system because it greatly has a effect on alternative ratio, total efficiency, knocking and catalyst efficiency. In the main, diesel injection timing is controlled regarding alternative ratio and knocking under high load. On the other hand, diesel injection timing is varied regarding exhaust gas temperature and catalyst efficiency under low load. As shown in the figure, CO_2 rises and NMHC decreases due to increase of thermal efficiency in upstream of catalyst according to advancing diesel injection timing.

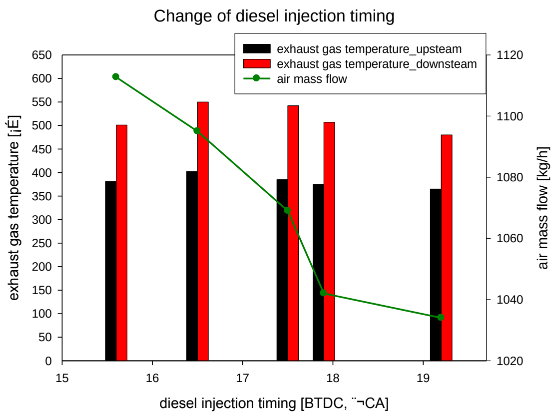

Fig. 10 Variation of exhaust gas temperature and air mass flow for change of diesel injection timing; 1600rpm 50% load

Conversely, CO_2 decreases and NMHC increases due to deactivation of catalyst efficiency in downstream of catalyst according to advancing diesel injection timing. When diesel injection timing is advanced, exhaust gas temperature decreases and catalyst efficiency deactivates too. Especially, diesel injection timing has a great effect on catalyst efficiency under low load because oxidation catalyst sensitively reacts to light off temperature.

Also, CO_2 can be all the more reduced by means of controlling diesel injection timing because air mass flow, which is a significant factor in calculation formula of ND-13 mode, is influenced by it.

On the other hand, if diesel injection timing is excessively retarded, catalyst efficiency declines due to combustion deterioration and decrease of exhaust gas temperature. Also, this totally results in increase of fuel consumption.

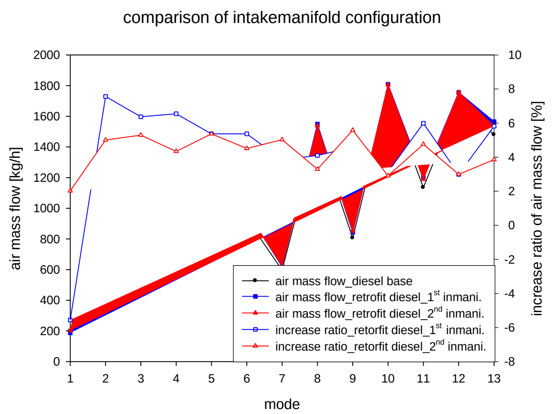

Fig. 11 Variation of air mass flow for deference of intake manifold configuration

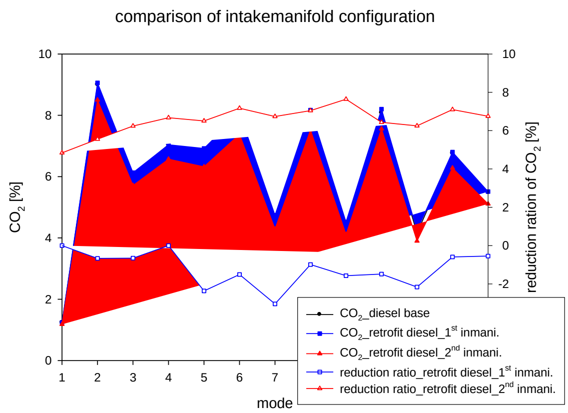

Fig. 12 Variation of CO2 concentration for deference of intake manifold configuration

Intake manifold configuration has a direct effect on combustion stability, distribution, homogeneity and the volumetric efficiency in dual fuel system because natural gas is supplied by mixer method. This paper evaluates variation of the volumetric efficiency and CO_2 for deference of intake manifold configuration. Figure 11 presents variation of air mass flow under ND-13 mode for intake manifolds of diesel base, 1st retrofit diesel and 2nd retrofit diesel. Air mass flow is closely related to CO_2 reduction because it is a significant factor in calculation formula of ND-13 mode. In case of retrofitting intake manifold, air mass flow rises about 5% than it of diesel base. This is judged on decrease of the volumetric efficiency caused by alteration of intake manifold configuration.

Figure 12 shows variation of CO_2 under ND-13 mode for intake manifolds of diesel base, 1st retrofit diesel and 2nd retrofit diesel. As shown in the figure, 1st retrofit diesel emits a similar amount of CO_2 compared to diesel base. On the other hand, CO_2 is reduced about 7% in case of 2nd retrofit diesel than diesel base. This is judged on alteration of combustion condition caused by intake manifold configuration. For reference, fuel consumption of each intake manifold is on an equal level.

In conclusion, dual fuel engine can effectively reduce CO_2 through variation of intake manifold configuration.

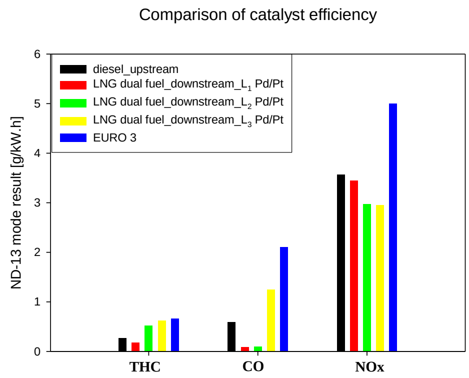

Fig. 13 Comparison of catalyst efficiency for P_d/P_t ratio; $L_1 > L_2 > L_3$

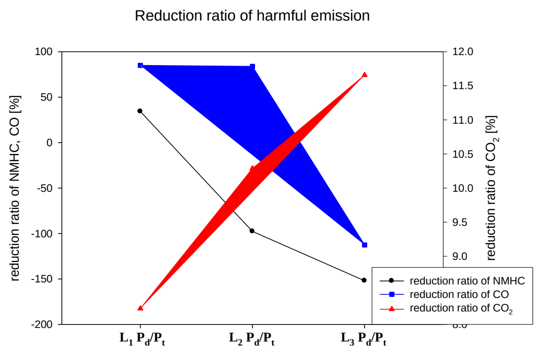

Fig.14 Comparison of reduction ratio for P_d/P_t ratio; $L_1 > L_2 > L_3$

Installation of oxidation catalyst in dual fuel system is essential to meet EURO 3 regulations. Dual fuel engine can reduce CO_2 about 20% in upstream of catalyst because C/H ratio is greatly lower than existing hydrocarbon-based fuel. Also, reduction of CO_2 is possible about 10% in downstream of catalyst through applying oxidation catalyst. In dual fuel system, reduction of CO_2, which is a main cause of the greenhouse effect, is very helpful in terms of protecting the environment. Especially, both P_d/P_t ratio and catalyst volume carefully must be selected because it has a great effect on catalyst efficiency, CO_2 reduction, cost and durability and so on.

Figure 13 shows variation of catalyst efficiency for alteration of P_d/P_t ratio. As shown in the figure, the more P_d/P_t ratio rises, the more catalyst efficiency increases. Also, dual fuel engine can meet EURO 3 regulations through changing P_d/P_t ratio.

Figure 14 shows relative reduction ratio of harmful emission in dual fuel system compared to diesel base. Optimizing P_d/P_t ratio is very difficult because there is a trade-off relation between NMHC and CO_2. For reference, when P_d/P_t ratio increases, economic feasibility is improved but durability for sulfur poisoning is deteriorated.

In conclusion, P_d/P_t ratio is very crucial factor for applying oxidation catalyst and must be varied in view of catalyst efficiency, cost and durability at the same time.

4. Conclusion

This paper showed dual fuel technology to reduce CO_2 in terms of engine control parameters, intake manifold configuration, catalyst efficiency.

1) In case of dual fuel engine, CO_2 reduction above 10% is possible through oxidation catalyst compared to diesel engine.

2) Alternative ratio carefully must be controlled to reduce CO_2 under low load because oxidation catalyst is sensitively

influenced by light off temperature.

3) Diesel injection timing is the most important factor in dual fuel system because it has a great effect on alternative ratio, total efficiency, knocking, catalyst efficiency, air mass flow. Therefore, CO_2 can effectively be reduced by means of controlling diesel injection timing.

4) Intake manifold configuration has a direct effect on combustion stability, distribution, homogeneity and the volumetric efficiency in dual fuel system because natural gas is supplied by mixer method.

5) P_d/P_t ratio must be optimized in terms of catalyst efficiency, cost and durability at the same time.

Reference

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