The Effects of Injection Methods and EGR on Combustion and Emission Characteristics of a Single Cylinder DISI Engine

Seoksu Moon[1], Jaejoon Choi[1], Essam Abo-Serie[1] & Choongsik Bae[1]

[1] Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, Korea

Keywords: Single injection, Split injection, Exhaust gas recirculation (EGR)

Abstract: Split injection has been known to reduce unburned hydrocarbon (UBHC) emission level and increase engine performance under certain operating conditions[1, 3]. Exhaust Gas Recirculation (EGR) is a common technique adopted for nitric oxides (NOx) reduction by the dilution of intake air, despite a sacrifice of simultaneous increase in UBHC and decrease in engine performance[2]. Thus, using split injection with adequate EGR may improve the emission level of UBHC, NOx and the engine performance compared to that of single-injection with or without EGR cases. The purpose of this study is to optimize the engine performance and emission levels at various engine operating conditions and injection methods when it is applied with EGR. The characteristics of single-injection and split-injection were investigated with various engine loads and EGR rates. The engine speed is changed from 800rpm to 1200rpm to investigate how the combustion characteristics are changing with increasing engine speed.

Figure 1 shows the experimental setup for the engine test. A piezo-electric pressure transducer (Kistler 6052B) was used to measure the in-cylinder pressure to calculate the indicated mean effective pressure (IMEP). Lambda and engine-out emissions were analyzed with a gas analyzer (Horiba MEXA 1500D). Slit injector and shell type piston bowl were used in the engine. Vertical intake manifold was installed to generate reverse tumble flow. Table 1 shows the experimental conditions for engine test. Engine load conditions are set to the low load (A/F=31) and middle load (A/F=24).

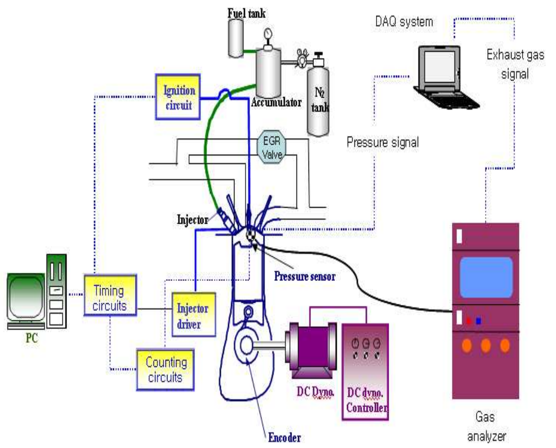

Figure 1. Experimental Setup for Engine

Table 1. Experimental Conditions

Engine Type	1 cylinder, 4 valves
Injector	Slit injector
Engine Speed	800rpm, 1200rpm
Air-fuel ratio (Injection mass)	31 (low load), 24 (middle load)
EGR rate	0%, 15%, 32%, 48%
Fuel	Gasoline
Injection and ignition timing	Minimum advance for best torque (MBT)

Minimum advance for best torque (MBT) was identified before comparing the characteristics for different injection methods and EGR rates.

Figure 2 shows the mass fraction burned (MFB) graphs for the two injection methods, at various air-fuel ratios and engine speeds. At engine speed of 800rpm, split injection shows lower burning speed than single injection at A/F 31, while split injection shows faster combustion in the early stage of combustion at A/F 24. Although split injection makes the mixture more homogeneous, the mixture near the spark plug could become leaner. It is thought that as the mixture gets leaner, the stoichiometric region near the spark plug is decreased at A/F 31 and increased at A/F 24. In the engine speed of 1200rpm, the difference between single and split injection is reduced and MFB graph gets similar. It is believed that this trend comes from the reduced time for formation of homogeneous mixture

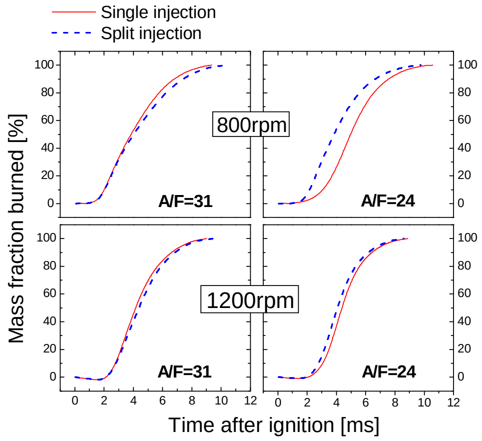

Figure 2. MFB graphs in various injection methods [800rpm and 1200rpm, EGR 0%]

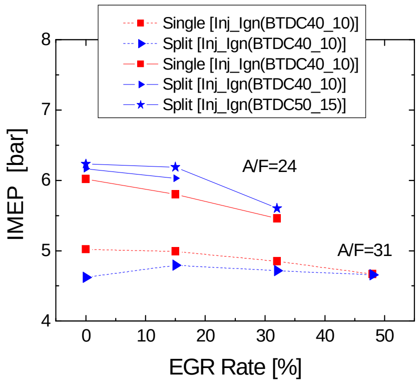

Figure. 3 Performance characteristics in various EGR rates and injection methods [800rpm]

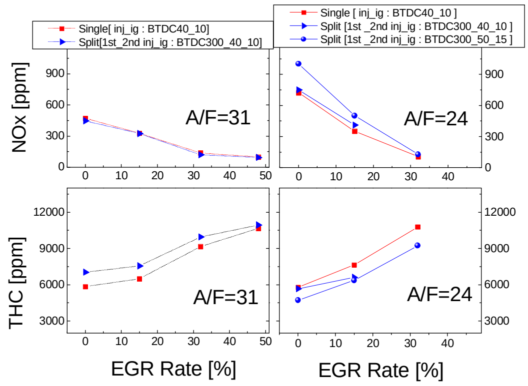

Figure 4. Exhaust Emission Characteristics in various EGR rates and Injection Methods [800rpm]

and increased turbulence caused by the augmented flow speed. In fact, more experiments investigating the changes of in-cylinder air flow pattern at higher engine speed are needed to confirm these explanations.

Figure 3 shows the engine performance data for single and split injection, and various EGR rates at 800rpm. The results show that IMEP decreases with increasing EGR rates which is mainly due to the reduced oxygen concentration in the mixture. This tendency is shown in all conditions. At A/F 31 condition, the split injection shows lower IMEP than single injection. This tendency could be attributed to the reduced burning velocity and heat release rate near the top dead center (TDC) caused by lean mixture close to the spark plug. However, the split injection shows higher IMEP at air-fuel ratio 24 and it is due to the increase of stoichiometric region near the spark plug.

Figure 4 shows the nitrogen oxides (NOx) and total hydrocarbon (THC) emission for various injection methods and EGR rates at 800rpm. NOx is decreased and THC is increased with increasing EGR rates. The main reason is that the dilution of mixture deteriorates the combustion and reduces the flame temperature[2]. In case of A/F 31, single injection shows less THC emission and almost the same NOx emission. However, in case of A/F 24 split injection shows less THC and more NOx emission[4]. As the EGR rate increases, the NOx emitted from single injection and split injection beomes similar. Mixture distribution and fuel concentration within the ignitable region close to the spark plug have great influence on both hydrocarbon and NOx emissions. Accordingly, there is a range of air-fuel ratio within which split injection can show higher performance and improved emissions when it is applied with proper EGR rate.

Figure 5 shows the performance and emissions for single and split injections at 1200rpm. Similar tendency could be found to that at 800rpm in A/F 31 where both IMEP and NOx are decreased while THC is increased in split injection. However, split injection and single injection show very similar performance and exhaust emissions for A/F 24 condition.

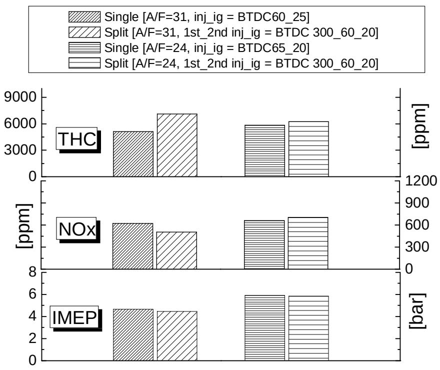

Figure 5. Performance and exhaust emissions in various injection methods [1200rpm]

The fast burning of split injection is significantly reduced and it becomes similar to single injection case as shown in Figure 2. It is believed that the characteristics of combustion in split injection will be very similar or worse comparing with single injection when the engine speed is increased. This tendency depends on the shape of combustion chamber and in-cylinder air flow.

Acknowledgement

The authors would like to thank the support of NRL (National Research Laboratory) project of Korea.

References

1) Jialin Yang, and Richard W. Anderson, 1998, Fuel Injection Strategies to Increase Full-Load Torque Output of a Direct-Injection SI Engine, SAE Paper 980495

2) Shizuo Sasaki et al., 1998, Effect of EGR on direct injection gasoline engine, JSAE Review 19, p223-228

3) Fuquan(Frank) Zhao et al., 2002, Automotive Gasoline Direct-Injection Engines, SAE, p.174-177

4) Noboru Miyamoto et al., 1994, Combustion and Emissions in a New Concept DI Stratified Charge Engine with Two-stage Fuel Injection, SAE Paper 940675