34 THC Oxidation Rate in Exhaust Manifold with Synchronized Secondary Air Injection

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A Synchronized Secondary Air Injection (SSAI) has been developed to reduce hydrocarbon emission by injecting secondary air intermittently into exhaust port. The method has been tested with SI Engine at cold idle condition. The object of this study is to analyze quantitatively the THC oxidation rate in exhaust manifold. The oxidation rate of time-resolved THC was investigated using the high speed THC analyzer and the individual hydrocarbon components were investigated using the gas chromatography. The effect of SSAI, air fuel ratio, spark timing, and air injection pressure on the hydrocarbon reduction and exhaust gas temperature in exhaust manifold has been investigated

***Keyword*: Engine Combustion, Pollution / Synchronized Secondary Air Injection (SSAI), High Speed THC Analyzer, Gas Chromatography, Hydrocarbon emission, HC oxidation rate**

1. INTODUCTION

In recent years, regulatory standards for vehicle emissions have become increasingly more stringent. To meet these stricter emissions regulations, research and development on after treatment system of exhaust gas as advanced exhaust emission control have become one of the most important subjects among car manufacturers. It is well known that the majority of the emissions measured from passenger car exhaust in the US Federal Test Procedure (FTP-75) are emitted within the first 90 to 120 seconds. During cold engine operation, the performance loss due to the significant fraction of the unburned fuel during normal combustion is substantially higher. Desirable reduction in the light-off time of catalytic converter can be achieved by Secondary Air Injection promoting the exothermic oxidation of HC components of the exhaust gas. The effect of Synchronized Secondary Air Injection (SSAI), air fuel ratio, spark timing, and air injection pressure on the hydrocarbon oxidation rate and exhaust gas temperature in exhaust manifold was monitored in SI engine at cold idle condition. The oxidation rate of time-resolved THC was acquired using the high speed THC analyzer and the individual hydrocarbon components were investigated using the gas chromatography.

2. EXPERIMENT

2.1 EXPERIMENRAL SETUP

Table 1 shows the specification of the test engine. The secondary air injection pipe (I.D. =6mm) was set up in exhaust manifold. The electrically driven solenoid valve controlled the secondary air injection time to synchronize the exhaust valve and the secondary air injector.

Table 1. Specification of test engine

Power-Train	1,975cc, DOHC
Compression Ratio	10.3 : 1
Valve timing	IVO/IVC/EVO/EVC (8/40/50/10)
Catalyst	MCC
Fuel control system	MPI

Fig. 1 shows the schematic diagram of experimental apparatus. A secondary air system, thermocouples, and sampling probes for high speed THC analyzer and gas chromatography were installed.

The point of secondary air injection is 1.5cm, ①, from the exhaust port. To measure exhaust gas along the exhaust manifold, the sampling probes were installed at l = 1.5, 5.5, 9.5 and 13.5 cm, ① ~ ④, where l indicated the distance downstream from

the exhaust port.

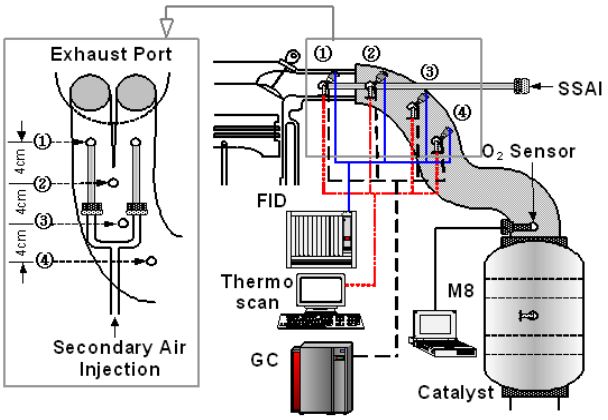

Fig. 1 Schematic diagram of experimental apparatus

2.1.1 Measuring Equipment

The fast response flame ionization detector (F-FID, Cambustion, HFR-400) was used to acquire the time-resolved THC concentration, in which the response time delay was shortened and the effect of exhaust pressure on the output signal was minimized by high vacuum pressure and a capillary sampling probe. Hydrogen fuel of 99% purity was supplied with 3 bar and pure air was supplied with 3.5 bar to make a flame for the F-FID.

The gas chromatography (GC, Hewlett Packard, 5890 series-Ⅱ) equipped with the recorder and the integrator, was used to analyze the individual component of the exhaust gas, in which the flux of the carrier gas in the column (AL2105) was controlled electronically. The flow in sampling loop was fixed with 0.5cm^3. The temperature was set up within 35 ~ 180℃.

2.2 TEST CONDITION

Table 2 shows the test condition of this study. Experiments were performed with the engine speed of 1200rpm and engine load was kept at idle state. The air-fuel ratio and the spark timing were varied to investigate the effect of engine operation condition.

Table 2. Test Condition

Engine Operating Condition	RPM	1200
	Coolant Temperature	30°C
	Load	Idle
	Equivalence Ratio	0.90 / 0.95 / 1.00
	Spark Timing (°CA BTDC)	10 / 15 / 20
SSAI Condition	Pressure (kgf/cm^2)	1.3 / 2.0 / 2.7

The secondary air injection pressures of 1.3, 2.0, 2.7kgf/cm^2 were used to monitor the air flow effect.

3. RESULTS

3.1 Exhaust gas temperature in manifold

3.1.1 Length and Spark timing

Fig. 2 shows the mixture temperatures of the injected secondary air and engine-out exhaust gas at each sampling point. All of the temperatures on sampling point ① with SSAI are lower than that without SSAI. It is due to the fact that the temperature of injected air is about 25℃. But the temperature with SSAI is higher than that without SSAI at sampling point ②, ③ and ④. The results suggest that the reaction between the secondary air and hydrocarbon of exhaust gas generates the oxidation energy, which makes the temperature high. The gradient of temperature between the sampling point ① and ② is steep. But the temperatures of sampling point ② and ③ are almost alike. The results suggest that the majority of hydrocarbon is oxidized between sampling point ① and ②. And the oxidation at the section of sampling point ② and sampling point ③ is kept up, but the oxidation rates of the sections of sampling point ③ and sampling point ④ are decreased.

These trends of temperature in exhaust manifold were shown similarly at the cases of other air-fuel ratio and spark timing. The temperature of all sections with spark timing of BTDC 10°CA is higher than that with spark timing of BTDC 20°CA. This implies that the quantity of engine-out hydrocarbon with spark timing of BTDC 10°CA is more plentiful than that with spark timing of BTDC 20°CA.

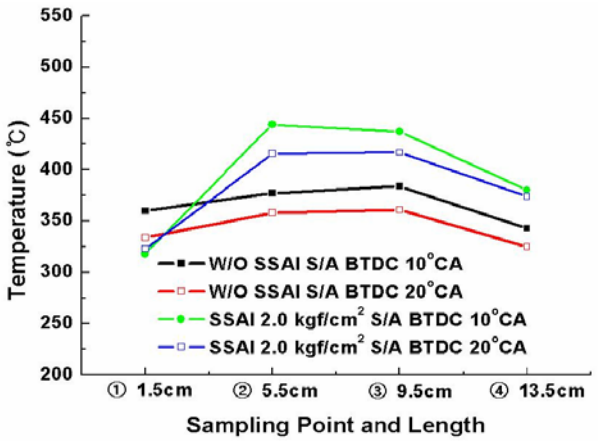

Fig. 2 Exhaust gas temperature on exhaust manifold at λ=1.00, S/A=BTDC 10, 20°CA with SSAI 2.0 kgf/cm^2 and without SSAI

3.1.2 SSAI Pressure

Fig. 3 shows the exhaust gas temperatures along the exhaust manifold with the SSAI pressure of 1.3, 2.0 and 2.7kgf/cm^2. As the injection pressure is increased to 2.0kgf/cm^2, the temperature in exhaust manifold rises. It is due to the quantity of the air which oxidizes the hydrocarbon. However in case of the injection pressure of 2.7kgf/cm^2, the temperature falls in the exhaust manifold on the contrary. This can be attributed to the fact that the quantity of the secondary air is too excessively injected. It seems that the majority of the injected air increased the temperature due to the oxidation of hydrocarbon but some portion which was not involved in oxidation decreased the temperature. It means that the pressure or the flow rate of SSAI should be optimized.

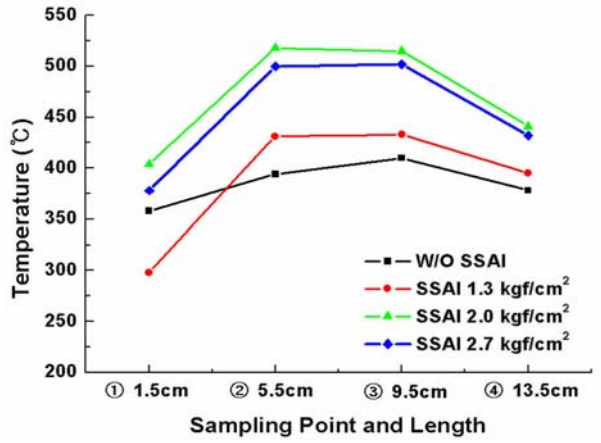

Fig. 3 Exhaust gas temperature in exhaust manifold at λ=0.90, S/A=BTDC 10°CA

3.3 THC concentration

Fig. 4 shows the time-resolved THC concentration on each sampling point, without SSAI and with SSAI pressure of 1.3, 2.0 and 2.7kgf/cm^2. The THC concentration decreases gradually along the exhaust manifold. When the SSAI pressure is 2.0kgf/cm^2, the THC concentration decreases most effectively to 6000ppmC$_1$ (reduction rate 45%).

3.3.1 THC concentration at various sampling point

Fig. 5 shows the THC concentration at each sampling point without SSAI. The maximum THC concentration at sampling point ①, 1.5cm is 12000ppm, but The maximum THC concentration at sampling point ②, 5.5cm decreases to 11300ppm, the maximum THC concentrations at sampling point ③, 9.5cm and ④, 13.5cm decrease each 10400ppm and 8700ppm. It means that the exhaust gas from the cylinder is oxidized along the exhaust manifold

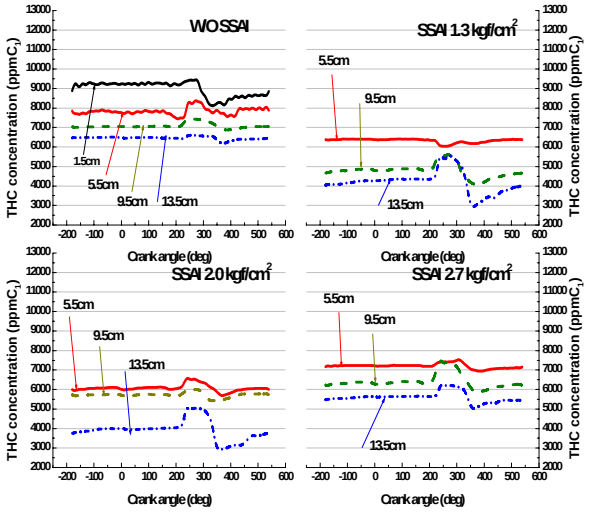

Fig. 4 THC concentration on exhaust manifold at λ=1.00, S/A= BTDC 10°CA

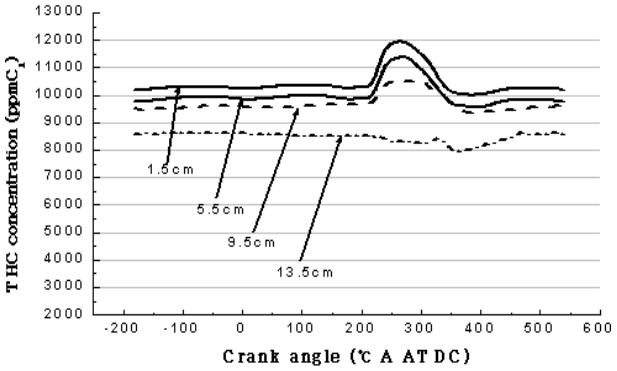

Fig. 5 THC concentration at λ=0.90, S/A= BTDC 20°CA

3.3.2 Effect of secondary air injection pressure

Fig. 6 shows the THC reduction rate at each SSAI pressure. The THC reduction rate is calculated by the maximum THC concentration without SSAI at sampling point ① to the maximum THC concentration with SSAI at sampling point ④. When the injection pressure is 2.0kgf/cm^2, the THC is most effectively reduced to 45%. This implies that; when the injection pressure is 1.3kgf/cm^2, the quantity of the secondary air isn't sufficient to oxidize the hydrocarbon efficiently. When the injection pressure is 2.7kgf/cm^2, the quantity of the secondary air is too much. So, the majority of the energy of exhaust gas is used to heat the secondary air instead of oxidizing the hydrocarbon. And the air and the exhaust gas are not sufficiently mixed. The exceedingly lean mixture can occur partially.

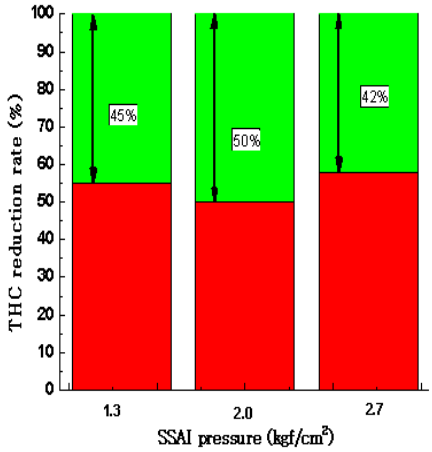

Fig. 6 THC reduction rate of the various Synchronized Secondary Air Injection at λ=0.90, S/A= BTDC 10°CA

Thus for the better effect minute case examination should be performed between 1.3kgf/cm^2 ~ 2.7kgf/cm^2.

3.3.3 Effect of spark timing

Fig. 7 shows the THC reduction rate of the case with equivalence ratio of 0.95, the SSAI pressure of 2.0kgf/cm^2 and the spark timing of BTDC 10°CA, 15°CA and 20°CA each. The THC reduction rate of the case of spark timing of BTDC 10°CA is the highest. This is attributed to the increased quantity of the unburned hydrocarbon in exhaust manifold since the spark timing was retarded. As a result, exothermic reaction is more active.

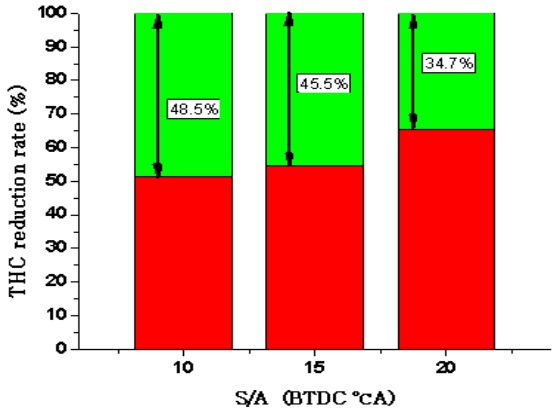

Fig. 7 THC reduction rate of the various spark timing

3.3.4 Effect of equivalence ratio

Fig. 8 shows the effect of the equivalence ratio on the THC reduction rate with spark timing of BTDC 10°CA and the SSAI pressure of 2.0kgf/cm^2. The case of equivalence ratio of 0.90 is most useful to reduce the THC concentration. As the unburned hydrocarbon got out through exhaust port increased due to excessive fuel the quantity of oxidation was also increased. Moreover the temperature of the exhaust gas is highest than those of other case of equivalence ratio. Therefore more THC could be oxidized easily.

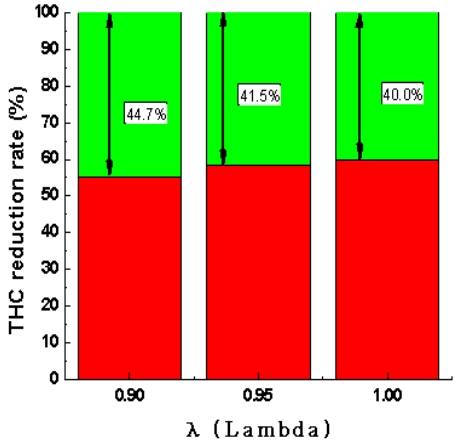

Fig. 8 THC Reduction Rate of various equivalence ratios

3.4 Individual HC component analysis

The individual components of the exhaust gas were analyzed on the sampling points ①~④ each, in exhaust manifold in case of with and without SSAI. From the above results the THC concentration was reduced most effectively in the case of equivalence ratio of 0.90, spark timing of BTDC 10°CA and SSAI pressure of 2.0kgf/cm^2 in this study. So the exhaust gas is analyzed by gas chromatography in this case.

Fig. 9 shows the chromatogram of the exhaust gas on the point of 1.5cm from the exhaust port without SSAI. Four components, A, B, C and D have more intensity than others. And then the oxidation rates of the components are calculated.

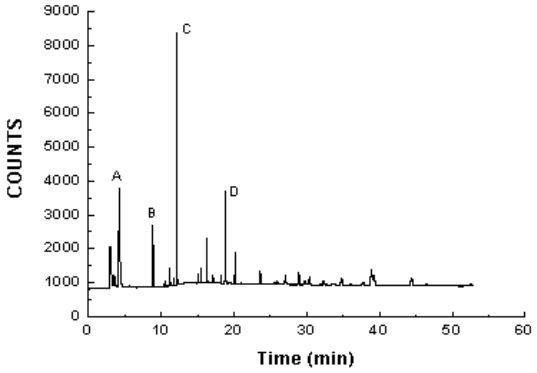

Fig. 9 Chromatogram on the point of 1.5cm from the exhaust port in exhaust manifold without SSAI

It was confirmed that the A component is methane, the B component is propyne, the C component is propane and the D component is iso-butane by analyzing the standard gas.

3.4.1 The oxidation rate of Methane

Fig. 10 shows the intensity of methane on each sampling point in case without and with SSAI. The SSAI is more useful to oxidize the methane. When the secondary air is injected the intensity of methane becomes lower gradually along the exhaust manifold. And the reduction rate of the methane is more increased as the sampling point is far from the exhaust port.

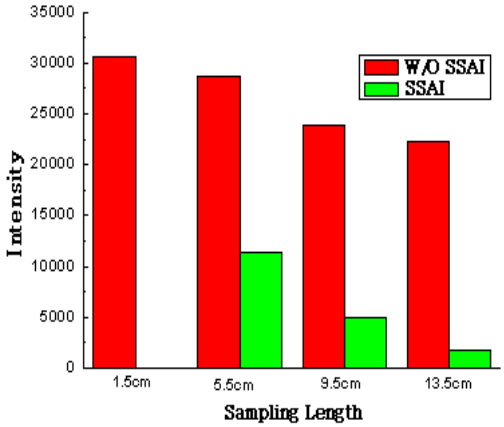

Fig. 10 Intensity methane of chromatogram at manifold

Table 3 shows the oxidation rate of methane. The oxidation rate of case with SSAI is 3~10 times, compare to that without SSAI. With SSAI, total oxidation rate is 84.9%, which is higher than that of THC oxidation rate.

Table 3 the methane oxidation rate

Sampling Point	W/O SSAI	SSAI
△(1.5cm - 5.5cm)	6.7%	63.1%
△(5.5cm - 9.5cm)	16.3%	56.9%
△(9.5cm - 13.5cm)	6.7%	65.1%
△(1.5cm - 13.5cm)	27.1%	84.9%

3.4.2 The oxidation rate of Propyne

Fig. 11 shows the intensity of propyne on each sampling point in case without and with SSAI. This case is almost like case of methane. But the intensity of propyne is lower than that of methane in each sampling point.

Table 4 shows the oxidation rate of propyne. The tendency of the oxidation rate of each section is like the case of methane. But without SSAI, The oxidation rate of the propyne is higher than that of methane in the sections of △(1.5cm - 5.5cm) and △(9.5cm - 13.5cm). As a result there exists less propyne than methane in the exhaust manifold however the oxidation rate shows similar trend.

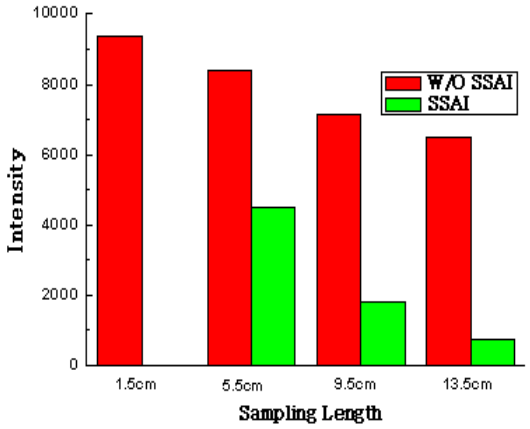

Fig. 11 Intensity propyne of chromatogram at manifold

Table 4 the propyne oxidation rate

Sampling Point	W/O SSAI	SSAI
△(1.5cm - 5.5cm)	10.5%	63.1%
△(5.5cm - 9.5cm)	15%	59.8%
△(9.5cm - 13.5cm)	10%	58.1%
△(1.5cm - 13.5cm)	30.8%	83.2%

3.4.3 The oxidation rate of Propane

Fig. 12 shows the intensity of propane on each sampling point in case without and with SSAI. The intensity and tendency of propane without SSAI is like with methane. But with SSAI, propane is more oxidized than methane.

Table 5 shows the oxidation rate of propane in each section. The oxidation rates of the sections of △(1.5cm - 5.5cm) and

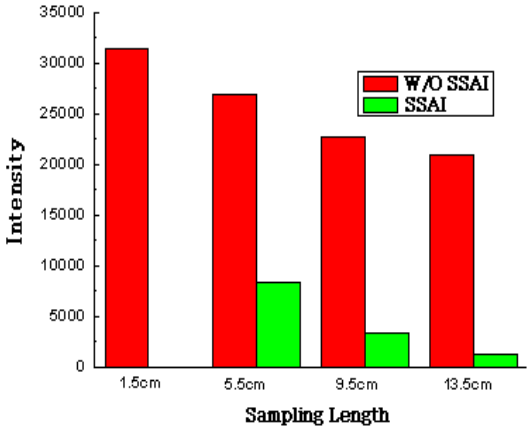

Fig. 12 Intensity propane of chromatogram at manifold

Table 5 the propane reduction rate

Sampling Point	W/O SSAI	SSAI
△(1.5cm - 5.5cm)	14.2%	73.3%
△(5.5cm - 9.5cm)	15.4%	60.1%
△(9.5cm - 13.5cm)	8.2%	64.7%
△(1.5cm - 13.5cm)	33.3%	85.9%

△(5.5cm - 9.5cm) are alike. With SSAI, the oxidation rate of propane is higher than those of other components.

3.4.4 The oxidation rate of Iso-butane

Fig. 13 shows the intensity of iso-butane on each sampling point in case without and with SSAI. The SSAI does not affect largely working of the oxidation of the iso-butane, compared to others.

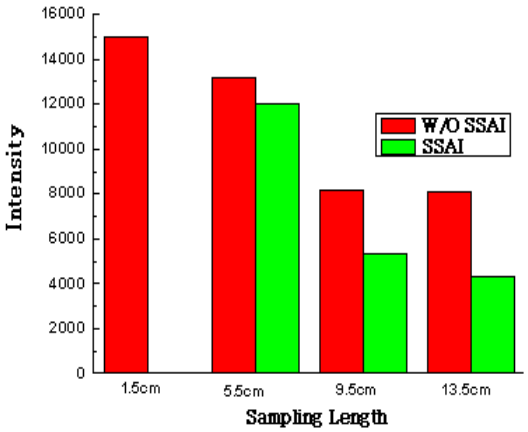

Fig. 13 Intensity iso-butane of chromatogram at manifold

Table 6 shows the oxidation rate of iso-butane. The oxidation rate in the section of △(5.5cm - 9.5cm) is much higher than that in other section. With SSAI, the oxidation rate of iso-butane is lower than that of other components. It is due to fact that the iso-butane has more carbons and molecular force than other components.

Table 6 The iso-butane reduction rate

Sampling Point	W/O SSAI	SSAI
△(1.5cm - 5.5cm)	12.1%	19.9%
△(5.5cm - 9.5cm)	38.4%	55.6%
△(9.5cm - 13.5cm)	0.5%	18.4%
△(1.5cm - 13.5cm)	46.0%	63.8%

4. CONCLUSION

(1) Time-resolved THC concentration shows that THC is almost oxidized in the section of 1.5cm ~ 9.5cm from the exhaust port. Also the exhaust gas temperature is the highest in same section due to the oxidation exothermic reaction.

(2) THC reduction rate was increased about 50% in case of the SSAI pressure of 2.0kgf/cm^2. But the secondary air pressure over 2.0kgf/cm^2 decreased the reduction on the contrary. It means that the pressure or the flow rate of SSAI is very critical factor to reduce the THC in exhaust manifold.

(3) As the spark timing is retarded from BTDC 20°CA to BTDC 10°CA, the THC oxidation rate increases to maximum 48%.

(4) The individual hydrocarbons speciation represents that the oxidation rate of methane, propyne, propane and iso-butane, is increased as the SSAI is applied. The oxidation characteristic of the iso-butane is lower than that of other components.

5. References

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