37 Characteristics of HC Emissions by Starting Conditions in an SI Engine

Seongsoo Kim

Silla University

San1-1, Gaebup-dong, Sasang-gu, Busan, Korea

During the SI engine starting up, starting conditions directly contribute to the unburned hydrocarbon emissions in spark ignition engines. The effects of catalytic converter temperatures and fuel injection skip methods on HC emissions were investigated. The test was conducted on a 1.5L, 4-cylinder, 16 valves, and multipoint-port-fuel-injection gasoline engine. To understand the formation of HC emissions, HC concentration was measured in an exhaust port using a Fast Response Flame Ionization Detector (FRFID). The result showed that HC emissions, which were emitted at the cold coolant and the catalytic converter temperature, were generated much higher than those of hot coolant and catalytic converter temperatures. In additions, fuel injection skips reduced highly HC emissions. It is convinced that optimized fuel injection skip method according to coolant and catalytic converter temperatures could be applied to reduce HC emissions during the SI engine startings.

***Keyboards*: SI Engine, HC Emission, Coolant and Catalytic Converter Temperature, Fuel Injection Skip, FRFID**

1. INTRODUCTION

Lately, the fuel economy of automobiles becomes a most important factor on account of the increasing fuel cost in the worldwide automotive market. And the producing proportion of hybrid cars is being increased with the advantage of the fuel economy. In additions, some conventional cars install idle stop functions to achieve higher fuel economy. The fuel economy of a car should be officially certified in a standard test cycle and the principal test cycle such as FTP 75 and ECE15+EUDC and Japan 11mode, has its own idle phase ratio over 17.9% of the test duration. Therefore it is reported that an idle stop car can reduce the fuel consumption in a certified test cycle and in a city driving. From the point of fuel saving, generally the required fuel quantity for an engine starting in SI engines would be similar with that for engine idle state during 7 seconds. Therefore, on the way of a city driving, an idle stop and restarting would be beneficial to fuel saving as vehicle stops for longer than at least 7 seconds.

But from the point of exhaust emissions, it should be considered the balanced effect of an idle stop on the fuel saving and uncontrollably generated exhausts emissions by engine restarting. And, it is difficult to control the highly generated exhaust emissions during an engine restarting. It is well known that there produced much hydrocarbon emission during a cold starting by cold parts of engine [1-3]. Especially at the initial stage of an engine starting, HC emission would be affected by the incomplete combustion, which caused by the cold layer of the combustion chamber wall and the incomplete mixing of fuel and air in the port [4-5]. And at the initial stage of an engine starting, additional fuel is injected to supply in-cylinder with rich mixtures beyond the conversion window of the catalytic converter, which ensures the success of an engine starting regardless coolant temperatures. Therefore almost engine out emissions during the starting pass through the catalytic converter without sufficient conversion reactions. So it caused to examine effects of more related parameters on exhaust emissions during the starting.

In this study, it is investigated effects of the temperature of the catalytic converter and the fuel injection skip including the coolant temperature on HC emission during an engine starting.

2. EXPERIMENTAL SETUP

The test was conducted on a 1.5L, 4-cylinder, 16 valves, and multipoint-port-fuel-injection gasoline engine. The engine specifications are described at table 1 and the schematic diagram is shown in Fig. 1.

A piezo transducer was flush mounted on the cylinder wall through the cylinder block. A UEGO sensor was mounted at the joint of the exhaust manifolds to measure the equivalence ratio. The data such as cylinder pressures, and coolant and catalytic converter temperatures, and HC concentrations, and fuel injector and spark signals were transferred to data acquisition system by every 2 crank angle degree and the tests started at intake TDC of cylinder 4. For the fuel injection skip, the fuel injector of cylinder 4 was controlled by the injection signals of Multi Function Engine Controller (MFECU 3208, Daintek. Co.) which connected with ECU. HC concentrations were measured in the exhaust port of cylinder 4, and in two points before and after the catalytic converter using a Fast Response Flame

Ionization Detector (FRFID, CAMBUSTION Co.). For the good response of HC concentration, the tips of sampling probes were positioned at 50mm away from exhaust valve stems in the exhaust port, and at 50mm before and after the catalytic converter in the exhaust pipe. The test engine was operated at stand-alone condition, which simulates the starting condition of an engine in a vehicle at "neutral" lever position of the transmission. The coolant temperature was controlled as 30℃, 50℃, 70℃, and 90℃ by a coolant temperature controller. The temperature at the mid point of the catalytic converter was controlled as 150℃, 200℃, and 250℃ by an engine running at the controlled coolant temperature.

Table 1 . Test engine specifications

Item	Specification
Engine type	IL 4 DOHC
Bore x Stroke (mm x mm)	76.5 x 81.5
Compression ratio	9.5
Displacement volume (cc)	1,498
Max. power (kW/rpm)	74 /6,000
Max. torque (Nm/rpm)	137 /3,000
Valve timing IVO(BTDC) / IVC(ABDC) EVO(BBDC) / EVC(ATDC)	8 °CA / 42 °CA 42 °CA / 8 °CA
Starter power (kW)	0.8

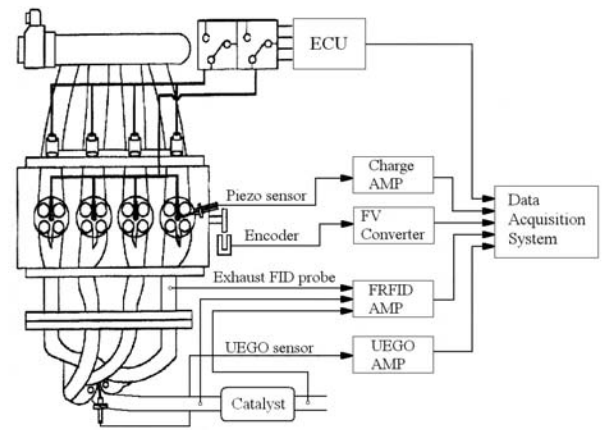

Fig. 1 Experimental setup

3. BASIC CHARACTERISTICS OF ENGINE STARTING

To understand the basic characteristics of an engine starting, engine speeds and equivalence ratios and fuel injection durations were measured. The engine speeds according to coolant temperature showed in Fig 2. The engine speed till 500 ms after the cranking start is nearly similar with cranking one and then it rapidly increased up to 1,600 ~ 2,000 rpm during 500 ~ 1,200 ms regardless of coolant temperatures. Remarkably, during 750 ~ 2,500 ms the engine speeds revealed obvious variations according to coolant temperatures. This means that the variations of engine speeds which resulted from piston-bore interface conditions, would affect on exhaust emissions, especially hydrocarbons emissions. Consequently, the tests were concentrated on the transient region within 3 sec after the cranking start. The equivalence ratio was measured using a UEGO at the junction of the exhaust manifolds where exhaust gas of the whole cylinders is mixed. It showed in Fig. 3. After the starting, the equivalence ratios displayed very low values, 0.5~0.6 of very lean mixtures at 600 ~ 750 ms and then till 900ms, the values rapidly increased up to 1.7 ~ 2.0 of very rich mixture, afterwards the values decreased gradually to 1.5 ~ 1.7 at 3,000 ms.

As shown in Fig. 2 and Fig. 3, at the coolant temperature of 30℃, the engine speed was the lowest and the equivalence ratio was distinctly variable. It definitely seem-

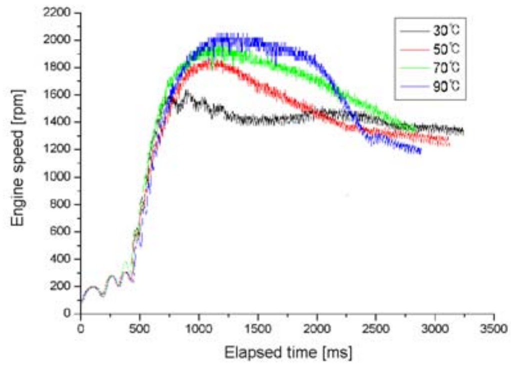

Fig. 2 Engine speed by coolant temperature at the starting

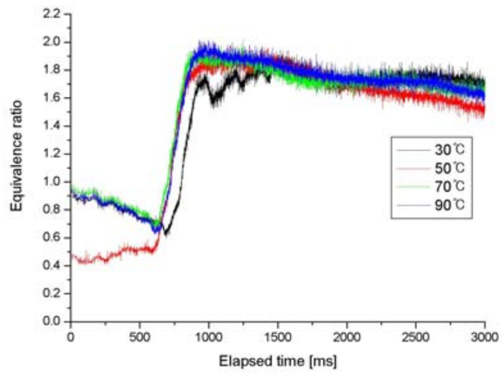

Fig. 3 Equivalence ratio by coolant temperatures at the starting

ed a serious condition for the complete combustion. Cylinder pressures and the equivalence ratio and the signals of fuel injector are shown in Fig. 4.

The 1st cycle is done without fuel injection and from the 2nd cycle, the fuel is normally injected at the exhaust phase of the 1st cycle and at the exhaust phase of the 2nd cycle, equivalence ratio started to quickly increase up to 1.8. It resulted from a complete cycle of every cylinder experienced its own firing phase with the normally injected fuel. Fuel injection durations are displayed in Fig. 5 and much fuel is injected to confirm the success of an engine starting. After 10 cycles, the durations approached stable ones and keep up different injection durations according to coolant temperatures. The higher coolant temperature is, the less the density of the intake air is and the less the required additional fuel is. Therefore the reduced fuel duration at higher coolant temperature showed in Fig. 5.

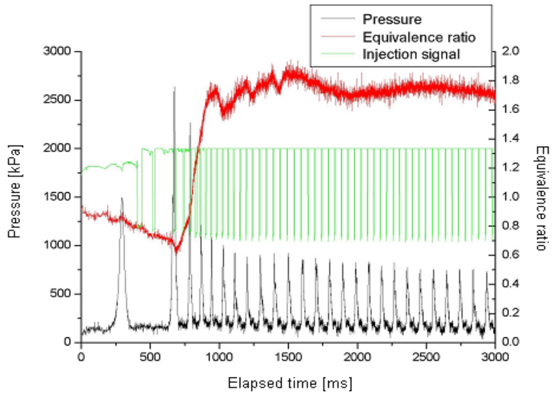

Fig. 4 Cylinder pressures and equivalence ratio and fuel injector signals at coolant temperature of 30℃

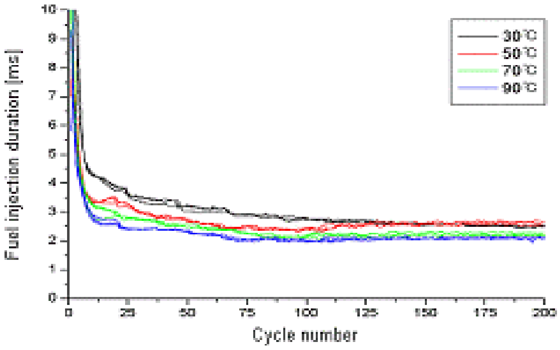

Fig. 5 Fuel injection durations by coolant temperatures at the starting

4. ENGINE OUT HYDROCARBON EMISSIONS

Engine out hydrocarbon emissions by coolant temperatures were measured at the exhaust port during engine startings as shown in Fig. 6.

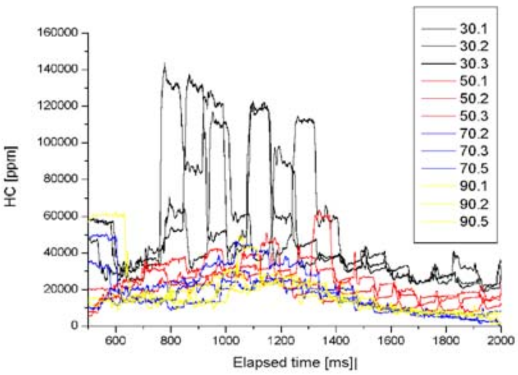

Fig. 6 HC emissions by coolant temperatures

The transient engine out HC emissions obviously and distinctly generated according to coolant temperatures within 2 sec after cranking start. The averaged HC emissions during 2 sec after cranking start are shown in Fig. 7. But it represents qualitative characteristics. With assumption of not much different mass of aspirated intake air throughout tests, it could be seemed as quantitative characteristics. On the base condition of coolant temperature of 30℃, the averaged engine out HC emissions reduced by 55% and 73% as coolant temperatures increased to 50℃ and over 70℃.

To reduce engine out HC emissions, it is confirmed that a coolant temperature is a key factor to control an idle stop. The conversion efficiency of catalytic converter depends on its temperatures and equivalence ratios of the supplied mixture. On the engine starting, the rich mixture is formed beyond conversion window of catalytic converter and its engine out emissions comes out without suitable reaction in catalytic converter although the temperature of the catalytic converter is over its light off temperature. Therefore it is not easy to control generated exhaust emissions during the initial phase of an engine starting. But it is necessary to investigate effects of coolant temperatures and catalytic converter temperatures.

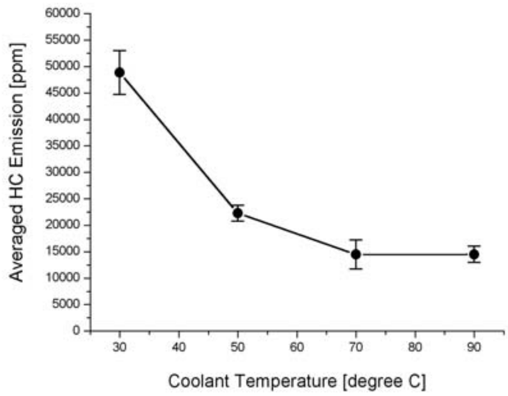

Fig. 7 Averaged HC emissions by coolant temperatures

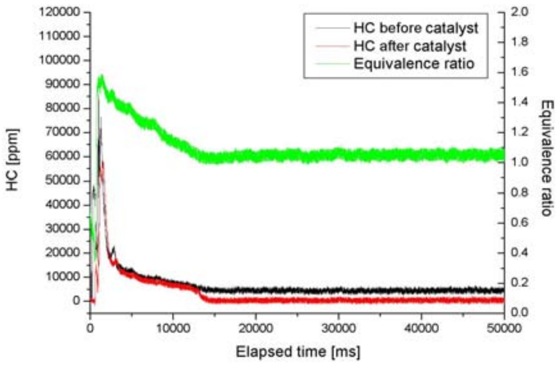

Fig. 8 The HC emission and the equivalence ratio at the coolant of 30℃ and the catalytic converter of 250℃

During an engine starting, it can be just considered how catalytic converter converts the engine out emissions of the rich mixture. The HC emissions before and after the catalytic converter were measured according to the coolant temperature(30℃, 60℃, and 90℃) and the catalytic converter temperature(150℃, 200℃, and 250℃). It is showed in Fig. 8, the HC emission and the equivalence ratio at the coolant temperature of 30℃ and the catalytic converter temperature of 250℃. As shown in Fig. 8, the HC emission was considerably generated to maximum 90,000 ppm during initial 3 seconds after an engine starting and then it gradually decreased to 5,000 ppm till about 15seconds. After 15 seconds, its value of 5,000 ppm was stably kept with the equivalence ratio of about 1.05. During 15 seconds after the starting there were very small but carefully countable differences of the HC emission between before and after the catalytic converter in spite of very rich mixture formation. After 15 seconds, there were obvious differences between before and after the catalytic converter. It means that the catalytic converter was activated the conversion reaction with the exhaust gas within the conversion window.

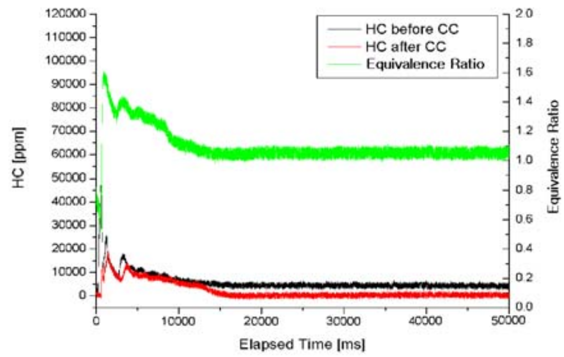

Fig. 9 The HC emission and the equivalence ratio at the coolant of 90℃ and the catalytic converter of 250℃

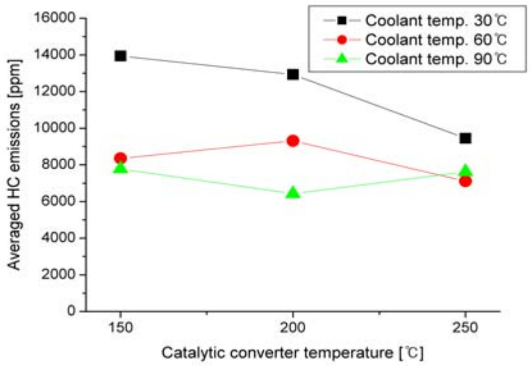

Fig. 10 Averaged HC emissions during 0-15 sec after the starting

The HC emission and the equivalence ratio at the coolant temperature of 90℃ and the catalytic converter temperature of 250℃ displayed in Fig. 9. The HC emission of maximum 25,000 ppm was generated at 2 seconds after an engine starting and from 4 seconds its concentration gradually decreased and after 15 seconds its value was stably kept with the equivalence ratio of about 1.05. Also during initial 15 seconds there were small but more countable differences of the HC emission between before and after the catalytic converter. After 15 seconds, there was similar behavior of the catalytic converter which showed at the coolant temperature of 30℃. The averaged catalytic converter out HC emissions according to temperatures of the coolant and the catalytic converter are showed in Fig. 10 and Fig. 11. As shown in Fig. 10, at coolant temperature of 30℃ the temperature of the catalytic converter would largely affect the averaged HC emissions, but at other coolant temperatures it was not so big influenced by the temperature of the catalytic converter. And on the basis of the HC concentration of 14,000 ppm at the coolant temperature of 30℃ and the catalytic converter temperature of 150℃, the reduced concentration by 5,700 ppm at the coolant temperature of 60℃ was larger than 4,500 ppm at the catalytic converter temperature of 250℃.

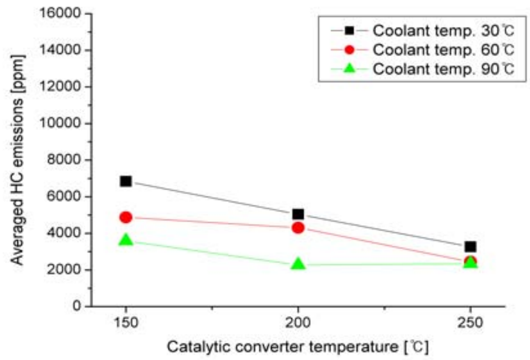

Fig. 11 Averaged HC emissions during 15-50 sec after the starting

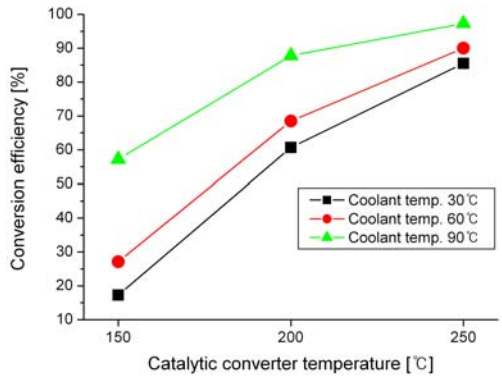

Fig. 12 Conversion efficiency of catalytic converter during 15-50 sec after the starting

On the basis of the coolant temperature of 30℃, it was found that the higher coolant temperature affected more on the reduction of HC emission than the catalytic converter temperature. But, On the basis of the coolant temperature over 60℃, the reduction of HC emissions was not so much influenced by the higher coolant temperature and the catalytic converter temperatures.

As shown in Fig. 11, the catalytic converter converted the engine out HC emissions by conversion capability according to its temperatures. With the mixture formation within conversion window, the function of the catalytic converter much more increased than that before 15 seconds. So, on the basis of the HC concentration of 7,000 ppm at the coolant temperature of 30℃ and the catalytic converter increased coolant temperatures and by increased catalytic temperature of 150℃, the reduced concentrations by converter temperatures were nearly similar. During 15~50 seconds, the conversion efficiency of the catalytic converter showed in Fig. 12. The higher coolant temperature is, the higher the conversion efficiency of the catalytic converter is. The higher exhaust temperature of higher coolant temperature might affect beneficially on the catalytic converter conversion capability at the same catalytic converter surface temperature.

5. FUEL INJECTION SKIP

It is absolutely necessary to reduce initially generated engine out HC emissions during engine starting for the good application of idle stop function. An application of a HC absorber, or a specified catalytic converter for the rich mixture may be a solution but its cost would not be negligible and the effectiveness should be confirmed.

On the way of experiments, it was found that the cylinders that were operated without fuel for several cycles before fuel was normally injected generated very low HC emissions. Because the first cycle with normally injected fuel would promote the combustion of in-cylinder mixture without the residual exhaust gas and large fuel droplets generated on the wetted wall of the intake port during previous cycles. And in addition, the following cycles could reduce the chilled layer effect due to the previous motored and the good combustion proceeded cycles.

To apply the fuel injection skip and to ensure a successful engine starting, two of the 4 cylinders are operated without fuel and the others with normal fuel injection during one cycle or three cycles. It is examined the effect of fuel injection skip on engine out HC emissions during an engine starting. The engine out HC emissions were measured by FRFID according to the coolant temperatures and the fuel skip cycles. The equivalence ratio and signals of fuel injector at 3-cycle fuel injection skip and coolant temperature of 90℃ displayed in Fig. 13.

The first injection signal appeared at the exhaust process of the 4th cycle. The first cycle is originally operated without the fuel and from the 2nd cycle, the fuel is normally injected as before shown in Fig. 4. The whole equivalence ratios and the engine out HC emissions according to the fuel injection skips are shown in Fig. 14. With the fuel injection skips, the equivalence ratio reduced and the engine out HC emissions reduced drastically. Although normally operated cylinder produced the highest HC emissions of 20,000~30,000 ppm during 750 ~ 1,500 ms, the engine out HC emission of 3-cycle injection skip was generated only about 10,000ppm. Moreover its exhaust gas within conversion window of the catalytic converter would be activated to convert in the catalytic converter.

Therefore, with 3-cycle fuel injection skip, the engine out HC emissions would reduce more according to the conversion capability of the catalytic converter. In addition, other components of exhaust gas such as CO and Nox could be converted in the catalytic converter by the formation of near λ=1.0 exhaust gas at the junction of the exhaust manifolds. Therefore, the 3-cycle injection skip would be more effective to reduce the engine out exhaust emission by lowly generated HC emissions and the conversion reaction in the catalytic converter.

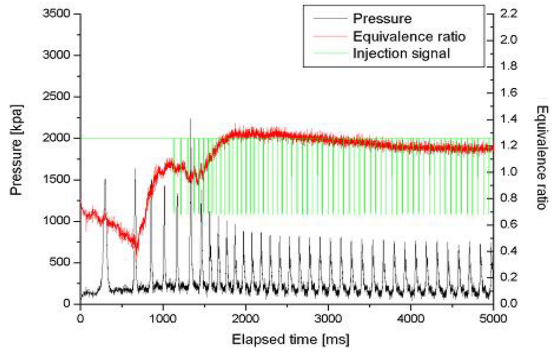

Fig. 13 Equivalence ratio according to fuel injections at 3 cycles fuel skip and 90℃ coolant condition

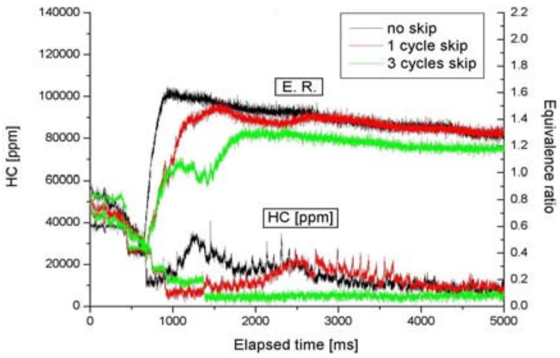

Fig. 14 Effect of fuel skips on HC emissions at starting at coolant temperature of 90℃

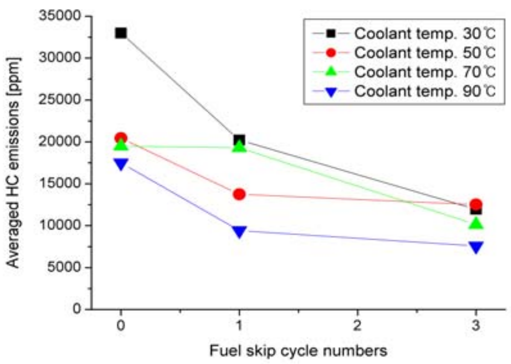

Fig. 15 Averaged HC emissions according to fuel skip cycle numbers

The averaged engine out HC emissions according to fuel injection skip cycle numbers are shown in Fig. 15. With the base condition of normal fuel injection, the engine out HC emissions reduced to 54 ~ 68% with 1-cycle fuel injection skip and to 36 ~ 61% with 3-cycle fuel injection skip.

It is confirmed that fuel injection skip has much favorable effects to reduce initially generated engine out HC emissions during engine starting and also has the possibility of conversion reaction by the formation of near λ=1.0 exhaust gas within conversion window. Finally it is suggested to apply the 3-cycle fuel injection skip to idle stop function to reduce exhaust emissions during an engine starting.

6. CONCLUSION

The characteristics of the engine out HC emissions during an engine starting were investigated according to the coolant temperatures and the catalytic converter temperatures and the fuel injection skip cycles. The results could be summarized as follows.

1) On the basis of the coolant temperature of 30℃, the averaged engine out HC emissions reduce by 65% and 80% as the coolant temperature increased to 50℃ and over 70℃. It is confirmed that a coolant temperature is a key factor to control an idle stop.

2) The initially generated HC emissions during engine starting were mainly affected not by the catalytic converter but by the coolant temperature. But, at the coolant temperature over 60℃ the reduction of HC emissions was not so much influenced by the higher coolant temperature and the catalytic converter temperatures. And during stable idle state, the catalytic converter converted engine out HC emissions by the conversion capability according to the temperature.

3) Fuel injection skip has favorable effects to reduce initially generated engine out HC emissions during an engine starting and also to let the exhaust gas be converted in the catalytic converter by forming the exhaust gas within the conversion window.

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