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AN EXPLORATORY STUDY OF THC EMISSION REDUCTION TECHNOLOGIES COMPLIANT WITH SULEV REGULATIONS

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ABSTRACT–This paper describes the development of THC reduction technologies compliant with SULEV regulations. Technologies embodied by the developmental work include improvement of fuel spray atomization, quick warm-up through coolant control shut off, and acceleration of fuel atomization for the fast rise of cylinder head temp inside the water jacket as well as the improvement of combustion state. The technologies likewise entail reduced HC while operating in lean A/F condition during engine warm-up with the cold lean burn technology, individual cylinder A/F control for improvement of catalytic converting efficiency, after-treatment such as thin-wall catalyst, HC-adsorber and EHC and etc, through vehicle application evaluation in cold start. We carried out an experimental as well as a practical study against SULEV regulations, and the feasibility of adopting these items in vehicle was likewise investigated.

KEY WORDS : SULEV, Coolant control, Air-shrouded injector (ASI), Improved exhaust manifold, Thin-wall catalyst, HC-adsorber, Hybrid catalyst, Electrically heated catalyst (EHC)

1. INTRODUCTION (Noriyuki *et al.*, 1999; Akira *et al.*, 1998)

Environmental pollution caused by vehicle tail pipe gas emissions has been recognized as a serious social problem, considering the rapid increase in the number of cars worldwide. These circumstances prompt lawmakers to fortify air pollution regulations with regard to vehicle gas emissions. CARB introduced LEV regulations in September 1990 and came into force starting with the 1994 model year. After the LEV I regulations, the ZEV's market ratio must be satisfied with a 2% share of the total market from 1998. However, because of the lack of strategic industries such as electric vehicle production, ZEV's sell duty from 1996 to 2003, and after that reformed to satisfy with 10%. CARB still decided to apply appropriate battery technology, supply of recharge station and other elements, CARB put off the performance of more severe LEV II programs from 2004 instead of the postponement of ZEVs market duty. The LEV II program sets up the average standard value of NMOG between 2004 and 2010, consolidates the NOx standard value of LEV/ULEV and includes the new SULEV in the Low Emission Vehicle category. It also sets up the middle stage between the ULEV and ZEV. New York and Massachusetts are both studying the viability of introducing the LEV II program by CARB. The Federal Government has also indicated signs of preparing a new exhaust gas control regulation plan, which will definitely have a big effect on the industry. As a result, carmakers from the USA, Japan and the EC are now studying various approaches to reducing exhaust gas pollution substances. Some makers have already developed and are ready to mass-produce the exhaust system that corresponds with ULEV regulations of the state of California. HONDA of Japan, in particular, utilizes the VTEC engine with an improved atomization injector, a 32-bit micro processor, precise A/F control and special catalyst system, and has developed the technology that meet SULEV regulations. NISSAN of Japan, on the other hand, applied SCV to intake manifold and made the best use of exhaust heat with dual wall exhaust manifold, and developed an exhaust gas reduction technology consisting of HC-Trap, high-performance TWC of thin-wall, and has publicized the entry of SULEV Sentra in the market.

But since many carmakers have not yet settled the technology of lowest stratum against SULEV regulation, industry has to contend with dependency on foreign technologies and ascending cost of technology transfer. The competitive power of pressure on price may be weakened with the advance into the world market. The

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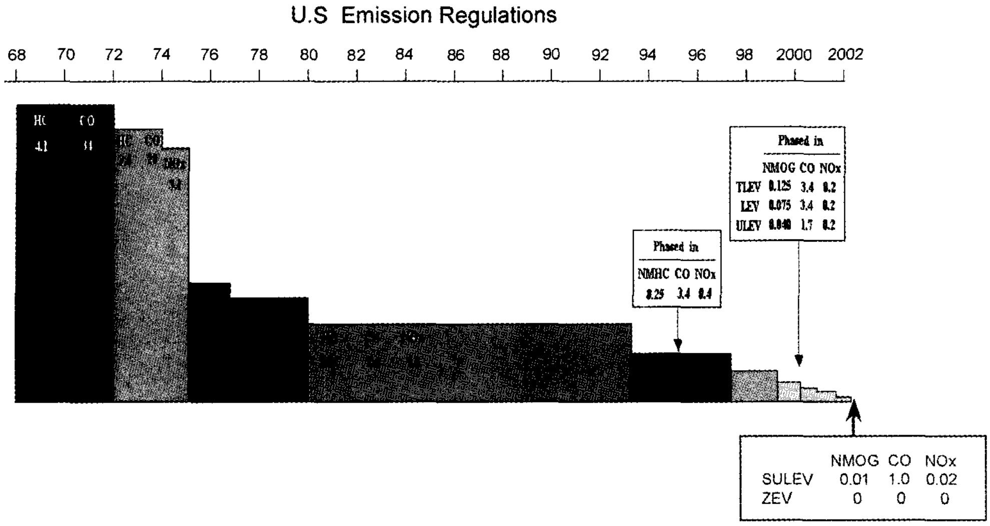


gasoline vehicle technology compliant with SULEV regulations will exert a beneficial influence not only on HMC's producing and exporting gasoline vehicle in the future, but also home industrial development, and ultimately contribute to Ultra-Low-Emission of air pollution.

This study sets the development of a practical system compliant with SULEV regulations as its primary goal. To carry this out, we shut off the coolant flow of engine in cold condition and accelerate fuel atomization for the fast rise of cylinder head temp inside the water jacket and the improvement of combustion state. We also reduced HC at lean A/F conditions during engine warm-up with the cold lean burn technology, and individual cylinder A/F control for improvement of catalytic converting efficiency, after-treatment such as thin-wall catalyst, HC-adsorber and EHC and etc, through vehicle application evaluation. We conducted the experimental and practical evaluation against SULEV regulations.

2. RESULTS AND DISCUSSION

2.1. Atomization of Fuel Spray

Generally, the reduction effect of raw THC decreases according to the increase in coolant temp. After the engine starts at idle the type of ② and ④ have the

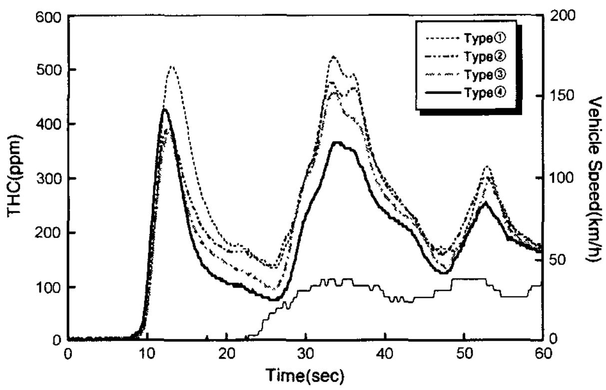


Figure 1. Vehicle raw emission concentration of fuel injector by types.

reduction effect of about 18~19% as compared with the type of ①. The type of air-shrouding specially represents a high reduction rate on driving section between acceleration and deceleration. This finding concludes that combustion is increased if fuel evaporation rate increased by reducing the size of droplet, relatively in case of the type of ② and in case of the type of ③ and ④ extent of fuel atomization is improved by air-shrouding, and amount of wall-wetting is decreased.

Table 1. Chief spec of fuel injector by types.

	Type ①	Type ②	Type ③	Type ④
Spray Angle (Cone Angle)	27° (17°)	20° (10°)	20° (10°)	23° (10°)
SMD (μm)	170	40	100	50
Air Flow Rate (kg/h)	–	–	0.5 at -65 KPa	1.56 at -67 KPa

2.2. Coolant Control

We installed an On/Off solenoid valve in front of the water-pump as shown in Figure 2, and completely cut off and partially change the flow rate of the coolant. In the position as shown in Figure 3, the thermo-couple was equipped for measuring temp rising width in cylinder head.

Figure 4 represents the flow rate profile in case of the coolant control; all shut off (0%), partial flow of 20%,

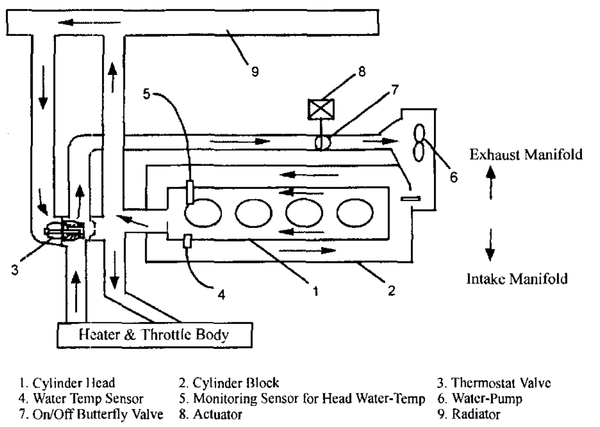


Figure 2. Coolant control system.

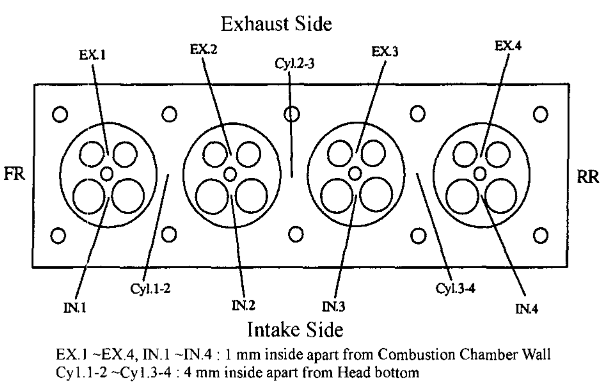


Figure 3. Install position of thermo-couples.

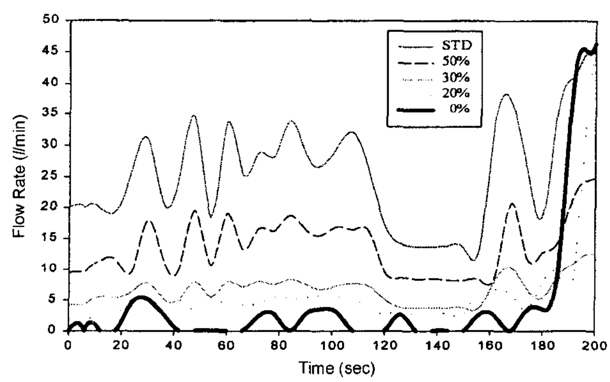


Figure 4. Flow rate profile of coolant control.

30%, 50% with use of the coolant control valve. After 200 secs when the water temp gets to 85°C, the flow rate is found to be 100% and from then on, each of them has the same flow rate profile.

A result of the vehicle test by coolant flow rate is that

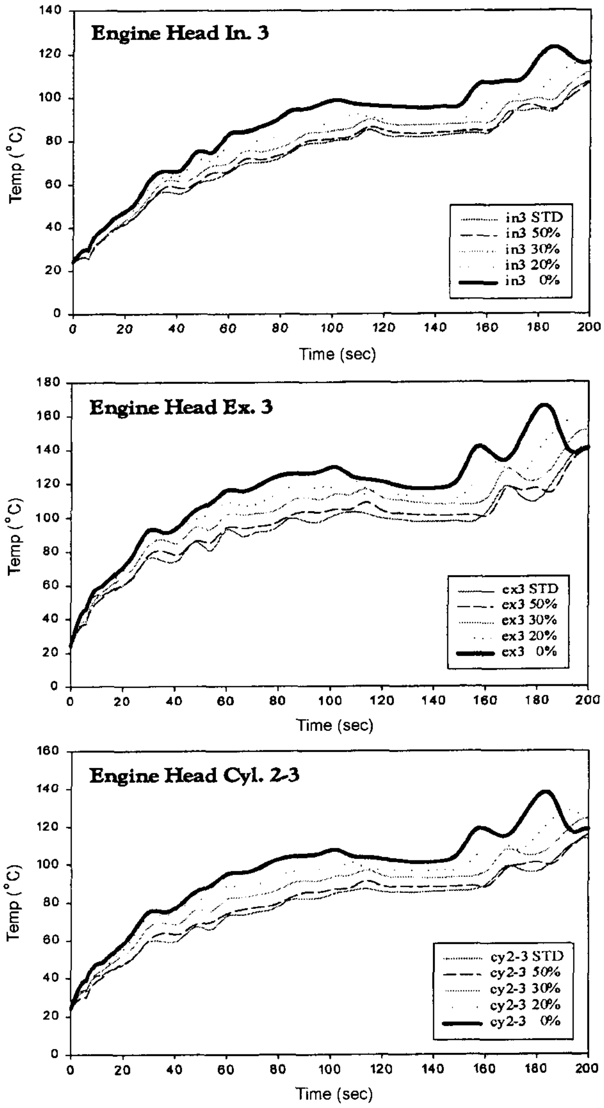


Figure 5. Temp profile of engine head by flow rate.

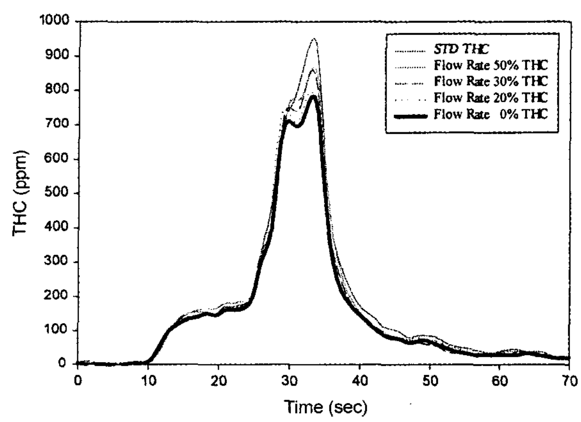


Figure 6. THC profile by flow rate.

the THC reduction effect of the 20% opening (as a result of THC reduction rate of 10.5%) is equal to the effect of complete shut off of coolant (THC reduction rate of 11.8%). The control of flow rate at levels of 30% (THC reduction rate of 4.4%) and 50% (THC reduction rate of 3%) shows slight reduction effects when compared to the standards. Therefore, though the coolant flows up to 20%, the reduction effect in the case of the completely closed off control can be expected. The rise in temp in the engine head is fastest in the test with completely closed off (flow rate 0%) control, while the temp slowly goes up at the set standard (flow rate 100%) (The change in flow rate corresponds to a linear width in temp rise.) The less the flow rate, the faster the temp of engine head goes up. This is attributed to the circulation flow rate of the coolant decreases, and consequently, the cooling effect of convection diminishes. The change in catalyst bed temperature due to the difference in flow rate almost does not exist and LOT of the catalysts does not appear to be shortened. The fact that the lower flow rate of the coolant (up to about 20%) causes reduction of the THC emissions and consequently – a reduced cooling effect. It can also be explained by the rapid rise in the temp of engine head

Table 2. Test condition of cold lean burn.

Case	Config.	Mapping Parameter
Case I	STD. (W/up ≠ 0)	–
Case II	Cold Lean (P/L AFR:16)	KFLF1, KFZW1, KFBAW, KFBAKL, FWLM1, TMRA1, 2
Case III	Cold Lean (P/L+Idle:16)	above items+KFLFL, fuel enrichment at shift of D range

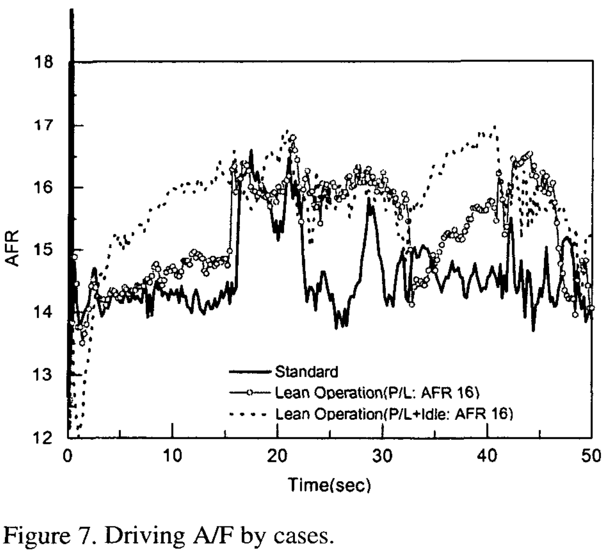


Figure 7. Driving A/F by cases.

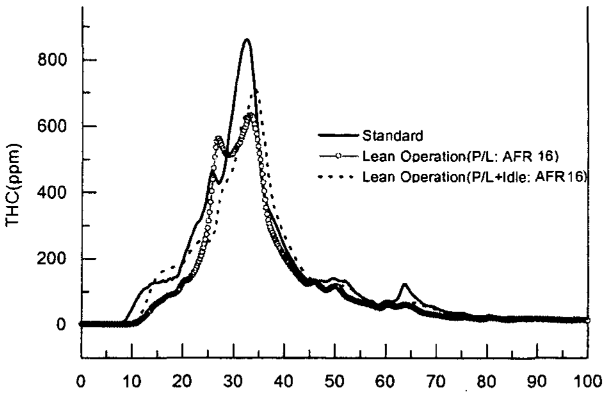


Figure 8. THC discharge characteristics of cold lean burn.

and the decrease in engine raw emission with combustion stability.

2.3. Cold Lean Burn

We installed the port-throttling device to the cylinder head and generate the swirl ratio for cold lean burn. It is the type of intake manifold gasket and lead out swirl on side of the port closing. Four small holes were made on the side of port closing to preventing fuel spray from wetting in the wall in response to the throttling device. In the case, the value of swirl ratio obtained is 0.58, and it is the value acquired only with intake port modification but without the MTV device.

The test condition is presented in Table 2, with the λ – closed loop control starting at 30°C on the basis of water temp in all cases. It is shown that the case of the standard is about 28 sec after the mode entry, but in the case of cold lean burn, it begins after 50 sec passed. Please refer to Figure 7 for the A/F ratio on the condition of driving when cold lean burn is applied, and in this case, the A/F right after mode cut-in (20 sec) is 16. Figure 8 represents the emitting characteristics of THC during cold lean burn according to each of the cases. The THC decreased to 20% just after the cold lean operation by utilizing a port-throttling device. It is explained that a swirl with port throttling promotes a rise in the combustion velocity, and it does much for more stable combustion in the end than cold state. In case of driving with A/F 16 up to idle, THC emission becomes slightly worse because of fuel enrichment (in the shift of N ⇒ D range), and deterioration of idle stability.

2.4. Air-gap Exhaust Manifold (Hiroshi *et al.*, 1999)

The air-gap exhaust manifold of SUS materials was made and experimented with during the vehicle test, and the results are as follows. Compared with the conventional exhaust manifold of FCD-H materials, all conditions with

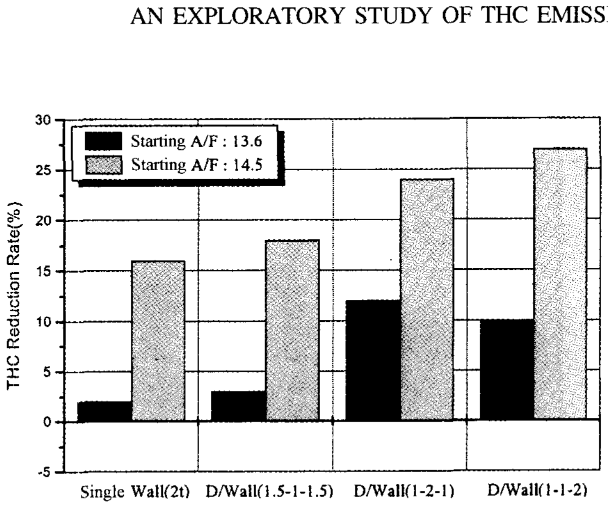


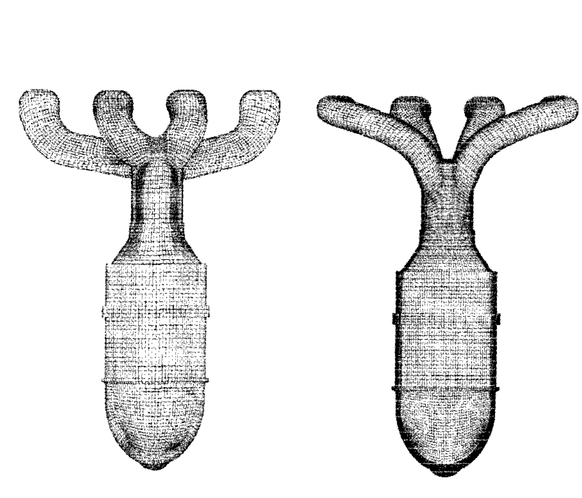
Figure 9. THC concentration change in starting A/F, 13.5 and 14.5.

SUS materials and thickness yielded a reducing effect even though there is a difference in effect following the engine start. In case of starting A/F 13.6, the THC decreased to 12%, while A/F 14.5 yielded a reducing effect on THC by 27%. It is for this reason that the heat loss in the exhaust gas goes down as a result of the adiabatic effect of the low heat conductivity of SUS materials, and the decrease in thermal mass following the reduction in thickness.

2.5. Flow Improved Exhaust Manifold (Hiroshi *et al.*, 1999)

The improved exhaust manifold is designed based on 4 perspectives: (1) Improvement of flow uniformity index (2) Selection of effective installation position of the oxygen sensor for cylinder A/F control (3) Restriction of increase in back pressure and (4) Shortening catalytic activation in initial cold condition. Figure 10 compared the shapes of the exhaust manifolds. The standard exhaust manifold using FCD-H materials showed an insignificant reducing effect of 5% and a cut-down on weight to 10%, with the shift to FCD-H into SUS materials. The THC reduced by 16% but the improved exhaust manifold using FCD materials through the shape alteration showed a high THC reduction rate of 56% as a result of the vehicle test of LA-4 mode compared with the standard type of FCD-H materials.

The major factors such as these are summarized in the following 3 cases.



(a) Standard Type (b) Improved Type

Figure 10. Shape comparison of exhaust manifold.

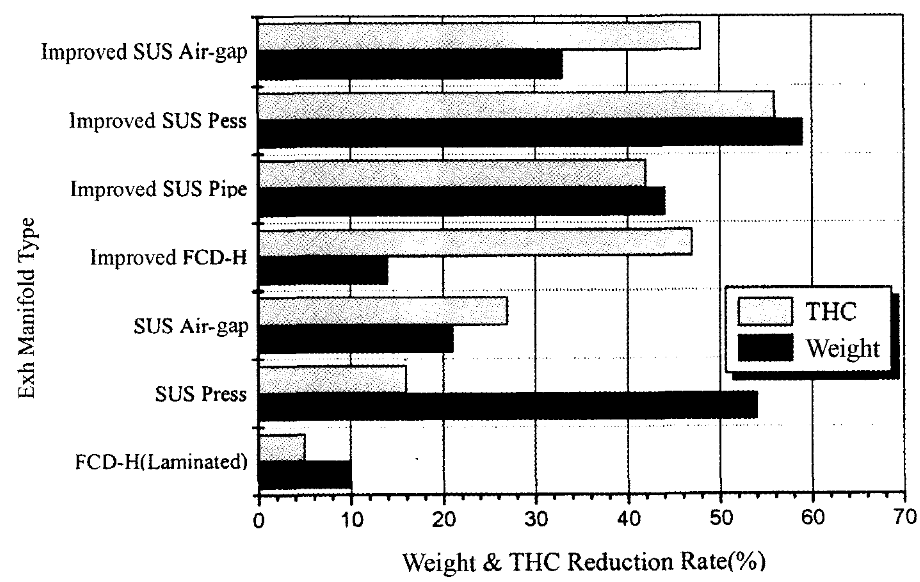


Figure 11. Change in THC and weight by exhaust manifold types.

Table 3. LOT of exhaust gas and CCC-bed (sec).

Type	Material/ Making		Exh-Gas	CCC _center	CCC _left	CCC _right
Std	FCD-H	Conv.	17	36	35	35
		Laminated	17	36	34 (1↓)	34 (1↓)
	SUS	Press	16 (1↓)	36	30 (5↓)	30 (5↓)
		Press Air-gap	(2↓)	(2↓)		
Imp	FCD-H		15 (2↓)	33 (3↓)	35	35
	SUS	Pipe	14 (3↓)	30 (6↓)	29 (6↓)	29 (6↓)
		Press	10 (7↓)	26 (10↓)	30 (5↓)	30 (5↓)
		Press Air-gap	12 (5↓)	27 (9↓)	30 (5↓)	30 (5↓)

(1) Improvement of flow at the junction part of and on the entrance of monolith.
(2) Each of the exhaust manifold's runner is shortened to 5~15%.
(3) Thermal inertia's reduction due to the cut-down on weight of exhaust manifold.

In case of the standard, the LOT reduction effect of the CCC-center is insignificant according to the change in materials and reduction in weight. The type of the improved manifold as compared with the standard has brought the rise in temperature of exhaust gas and CCC-center to about 50~100°C, while LOT shortening with FCD-H is 3 sec and SUS is 10 sec. In THC reduction and LOT shortening of catalyst, the improvement effect of exhaust gas flow following shape modification is more critical than the reduction effect of thermal inertia according to the change in material and weight of the exhaust manifold.

2.6. Individual Cylinder A/f Control (Jeff *et al.*, 1999; Yusuke *et al.*, 1994)
The Air-Fuel ratio is measured in each exhaust-gas manifold runner to yield any differences. The results are presented in the figure. The difference obtained is varied with engine speed and is particularly maximized during idle state. Figure 12 indicated the result of the difference on idle state. When engine speed drops lower than 800 rpm, the difference is high. The slower the speed, the greater the difference. Therefore, considering the trend of idle speed being low, it is more necessary to control individual Air-Fuel ratio.

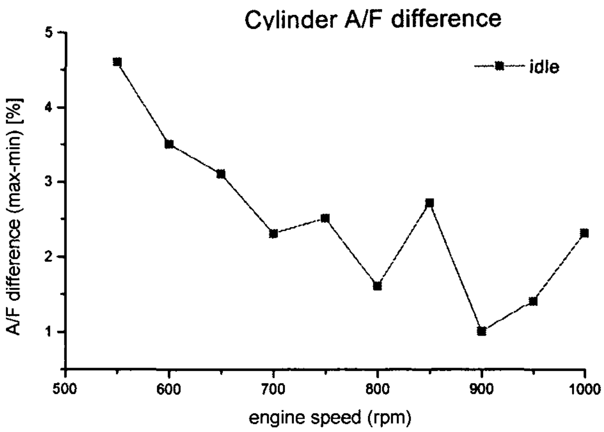


Figure 12. Cylinder A/F difference.

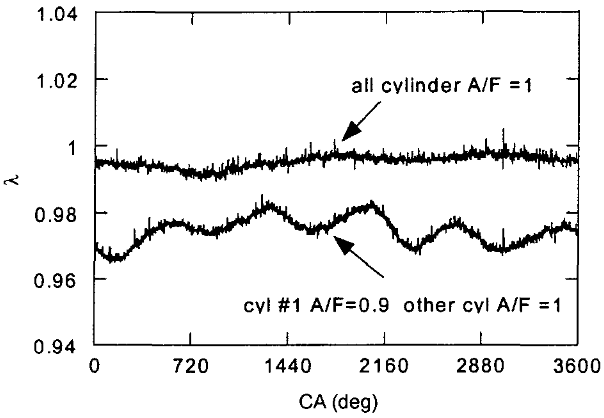


Figure 13. O_2 Sensor output signal at the confluence point.

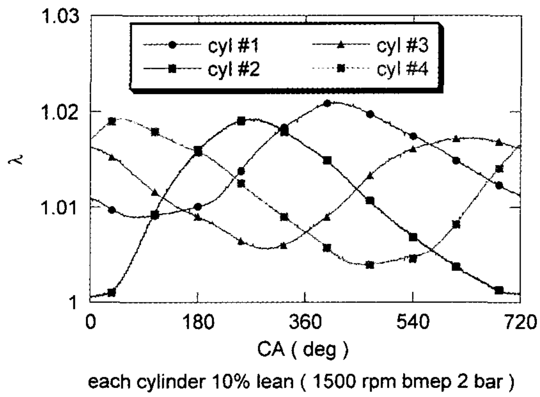


Figure 14. Comparison with O_2 sensor output signal at the confluence point in the case of one cylinder 10% lean.

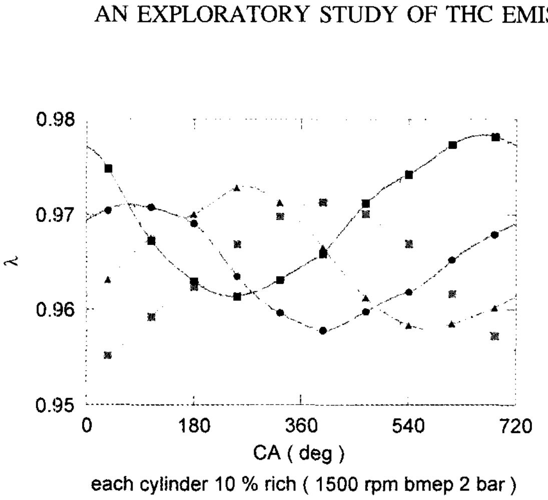


Figure 15. Comparison with O_2 sensor output signal at the confluence point in the case of one cylinder 10% rich.

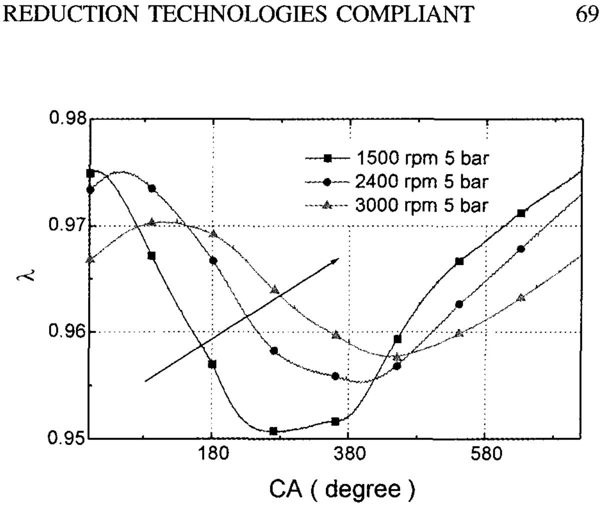


Figure 16. O_2 sensor characteristics change by the A/F differences the engine speed increases.

In general, the Wide-band O_2 sensor has a time constant range of 60~120 msec, which is slow compared to the engine firing frequency. Therefore, the signal processing about the output of O_2 sensor is needed to control on the basis of the O_2 sensor. First of all, let us study the output pattern of the O_2 sensor. Figure 13 is the obtained result from the O_2 sensor signal by the crank angle at the exhaust manifold confluence point in case that all cylinder A/F ratios are stoichiometric and only one cylinder A/F is 10% rich. The signal of O_2 sensor is changed by the cycle when A/F of one cylinder is 10% rich.

The ensemble average of 100 cycles shows that there is about 180° difference of phase in the cylinder. Likewise, there is a 360 degree difference of phase when there is a 10% increase or decrease in fuel quantity. When rich, the information on the A/F ratio about the cylinder is contained at the maximum value of pole, and in case of being lean – at the minimum value of pole. This information on the A/F ratio differs from the driving condition of engine speed and load. The influences of engine speed and engine load are illustrated in Figures 16

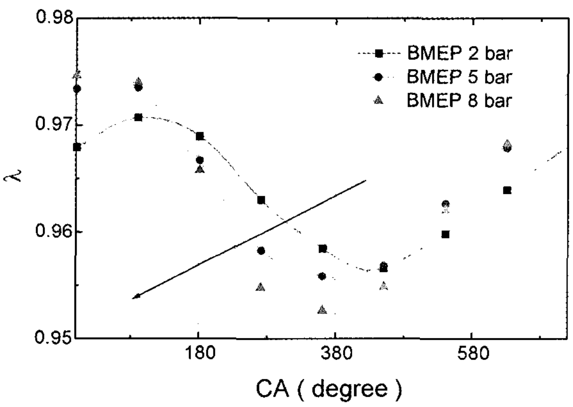


Figure 17. O_2 sensor characteristics change by the A/F difference as engine load increases.

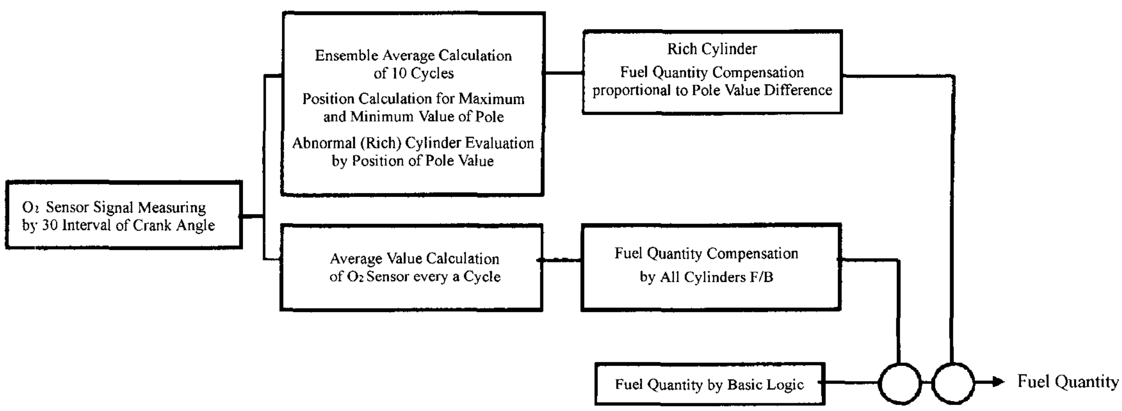


Figure 18. Flow chart of individual cylinder A/F control logic.

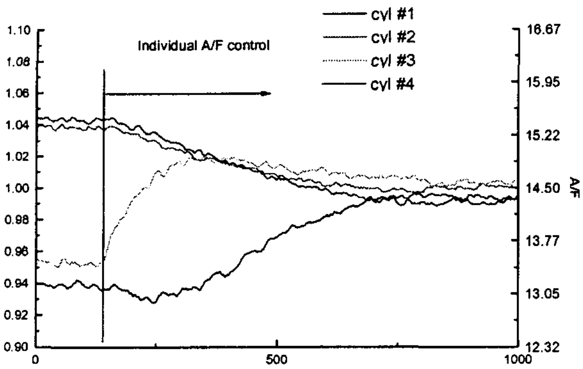


Figure 19. Test result of individual cylinder A/F control.

and 17. The position of the pole value containing the information on the cylinder is advanced with the increase in engine speed, and is retarded with the increase of engine load. The level of amplitude against the difference in the A/F ratio would be small when the engine speed is set at fast or the engine load is decreased.

The individual cylinder A/F control is carried out with the use of the position and amplitude in the pole value among the output of the O_2 sensor. In summary, it is discriminated in such a way that only the richest cylinder based on the output of the O_2 sensor in the confluence point value within the one cycle from the position of pole and is compensated for fuel quantity. The flow chart is the same as Figure 18. Figure 19 is the result of the individual cylinder A/F control based on this logic. The rich cylinder of no.3 is first controlled on the basis of logic property, while the lean cylinder of no.2 and no.4 increase the fuel quantity by the average value control logic. On the logic of P-I-D control, the P value in the engine driving condition is to be determined. By such control, it is well-controlled within 2%.

2.7. Thin-wall Catalyst (Douglas *et al.*, 1999; Shinichi *et al.*, 1999)

The LOT is shortened, when THC and NOx are reduced in thin-wall catalysts. The shortening of LOT is primarily because of the decrease in thermal mass in the reduced wall thickness between cells, as well as due to the improvement in conversion efficiency as GSA increases. As cells compress or spread out depending on the increase in cell density, it takes less time for the exhaust gas to reach the active site of catalysts. Also it is gathered that with the decrease in thermal mass, warm-up performance in initial cold start (LOT) is improved. Figure 20 shows the comparative vehicle test results between oval type

Table 4. Fundamental properties of standard and thin-wall ceramic substrate.

Cell Structure, cpsi/mil	400/6.5	600/4	900/2
Wall Thickness, mm	0.17	0.11	0.06
BD, g/cm^3	0.43	0.38	0.28
(%)	(100)	(88)	(65)
GSA, cm^2/cm^3	27	34.3	43.7
(%)	(100)	(127)	(161)
OFA, %	75	79	86

Table 5. LOT of exhaust gas and CCC-bed (sec).

Cell Structure (cpsi/mil)	Exh Gas	CCC _center	CCC _left	CCC _right
400/6.5	16	35	33	33
600/4	↑	30 **(5↓)**	29 **(4↓)**	30 **(3↓)**
900/2	↑	26 **(9↓)**	25 **(8↓)**	25 **(8↓)**

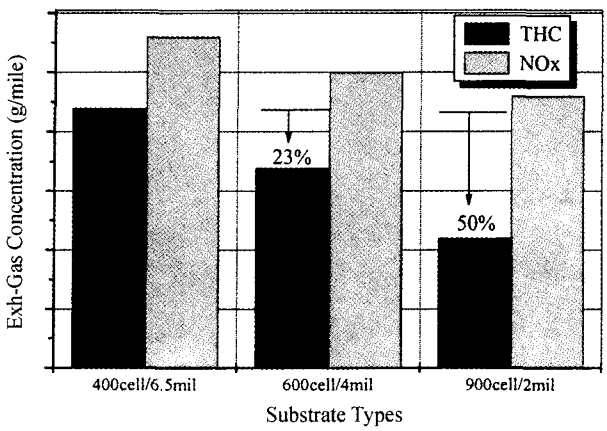


Figure 20. Test result of thin-wall catalyst.

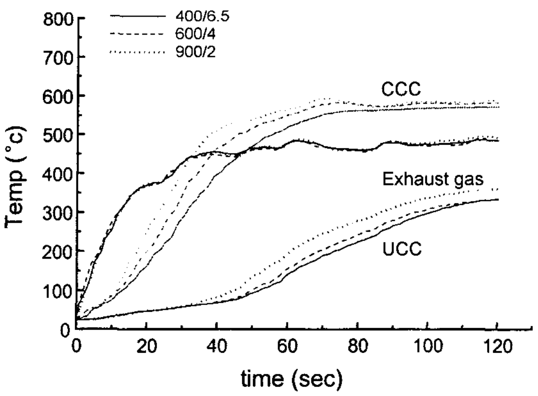


Figure 21. Temperature curve of exh-gas and catalyst.

thin-wall catalysts (600/4, 900/2) and conventional-standard catalysts (400/6.5). The temperature characteristics of CCC, UCC and exhaust gas in initial engine start are the same as shown in Figure 21. Due to thin-wall cell thickness, LOT of CCC reduced to 5 sec, 9 sec at 600 cell and 900 cell, respectively. The center temp of the substrate bed, including the left and right sides, represents an equal distribution.

2.8. Hybrid Catalyst

The hybrid catalyst has a double layered structure consisting of a HC adsorption layer (bottom) and a three-way catalyst layer (top). HC is adsorbed when the catalyst temperature is low, and the adsorbed HC is desorbed when the catalyst temperature rises. Then, as the temperature rises further, the three-way catalyst activates to convert the desorbed HC. These characteristics place the success or failure of hybrid catalysts under the control of activation in low temperature (Light-Off characteristics) of TWC coated on the top layer. In the case of CCC, the activation characteristics of low temperature is vital that herewith all studies are centered on the development of

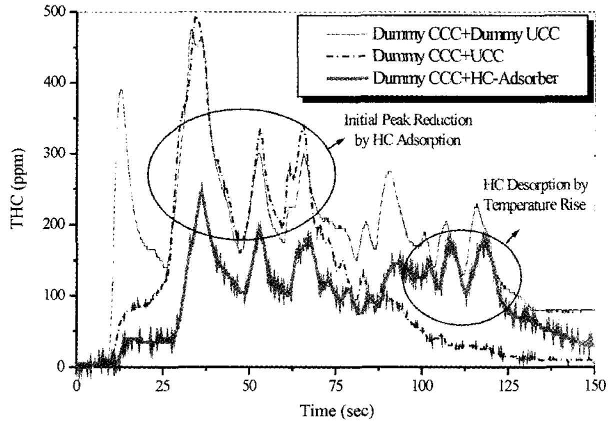


Figure 22. THC adsorption effect of HC-adsorber.

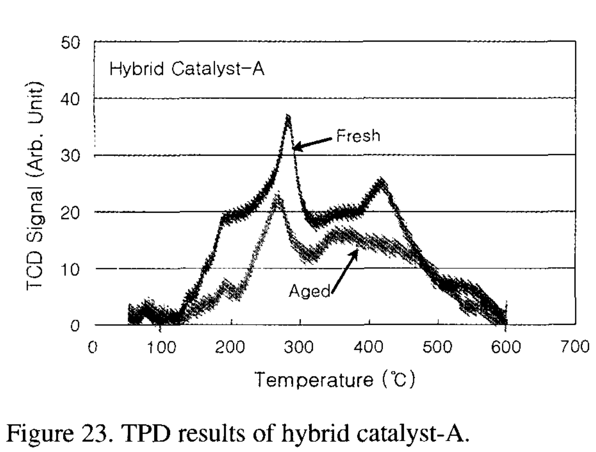


Figure 23. TPD results of hybrid catalyst-A.

catalysts with satisfactory achievement of low temperature. Figure 22 represents the effects of the HC-adsorber.

Figure 23 and 24 show the TPD (Temperature Programmed Desorption) results of two hybrid catalysts. The hybrid catalysts were aged at 850°C in air conditioned furnace for 50hrs to observe the deactivation effect of HC adsorbers. It is thought that the TCD peak at 270~280°C stems from the HC adsorber and that above 400°C stems from the three-way catalyst. Based on the TCD peak areas of fresh and aged hybrid catalysts, the amount of the HC adsorption for hybrid catalyst-B is more than that for hybrid catalyst-A. And in comparison with fresh catalysts, HC adsorption performance of hybrid catalyst-A and B after aging were decreased 35% and 26%, respectively. This means that an improved HC adsorber is used in hybrid catalyst-B. In comparison with the desorption temperature of adsorbed HC, the desorption of the adsorbed HC was started at around 150°C for hybrid catalyst-A, on the other hand, the starting temperature of HC desorption for hybrid catalyst-B was up to around 230°C. This indicates that HC conversion of hybrid catalyst-B is more effective than that of hybrid catalyst-A. Synthetic gas tests shows that the 50% conversion temperatures of HC for hybrid catalyst catalyst-A and B were 276°C and 221°C, respectively. With hybrid catalyst-

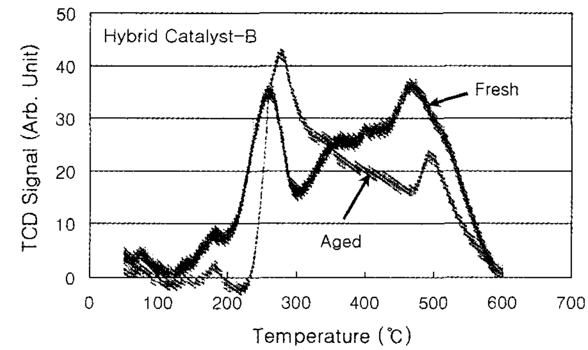


Figure 24. TPD results of hybrid catalyst-B.

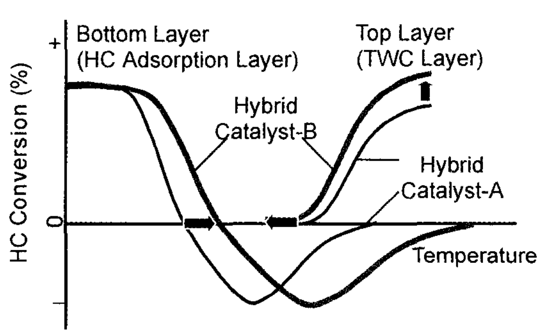


Figure 25. Characteristics of the hybrid catalyst.

B, three-way catalyst (top layer) was already activated when the desorption of adsorbed HC was started at HC adsorption layer. Detailed test apparatus and procedures are described elsewhere. Figure 25 shows the characteristics of the hybrid catalysts. In summary, the improved hybrid catalyst-B had more HC adsorption and higher desorption temperature and better three-way catalyst efficiency than those of hybrid catalyst-A.

2.9. Metallic Catalyst

Two substrates, metallic one with 600 cpsi/30 μm and ceramic one with 900 cpsi/2 mil, of identical volume and washcoat composition have been compared to examine the applicability of the metal catalyst. In the cold phase of the FTP test, the NMHC emission of metallic substrate was 0.012 g/mile which was 42% higher than 0.007 g/mile of that of the ceramic one. Initial activities of the catalysts were investigated by monitoring the temperature profiles.

As shown in Figure 26, the bed temperature exceeded the inlet gas temperature after initial 20~30 seconds. With both catalysts, it is also observed that the first brick already warmed up to 500°C after 30~40 seconds. Times required to reach some temperatures are summarized in Table 6. As the light-off temperature (LOT) is generally around 300°C, time to this temperature may be used as an efficiency of initial activity. At the 1st brick, it took 23 seconds for the metallic substrate while that for the ceramic one was 20 seconds. At the 2nd brick, it took 40 seconds and 35 seconds each, to give the difference of 5 seconds.

Table 6. LOT characteristic for two types of monoliths.

Time (sec)	1st brick		2nd brick	
	Metal	Ceramic	Metal	Ceramic
200°C	18	14	33	31
300°C	23	20	40	35
400°C	30	25	47	40

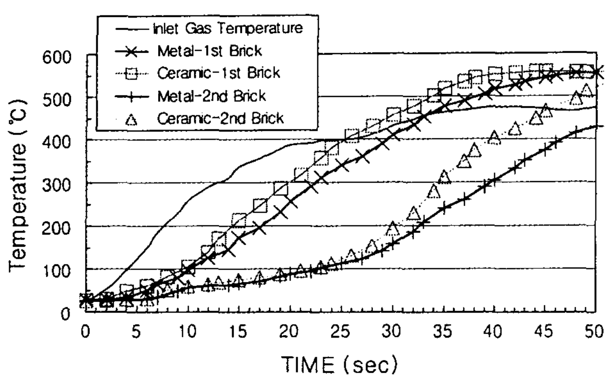


Figure 26. Temperature profiles of ceramic and metallic catalysts.

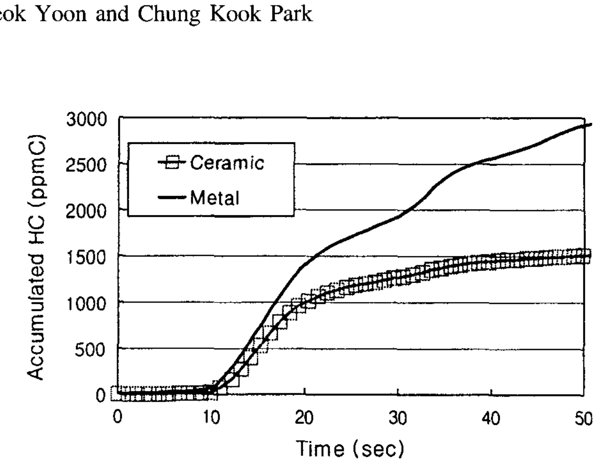


Figure 27. Accumulated HC using ceramic and metallic catalysts.

The difference can explain the accumulated HC emission results presented in Figure 27, which shows the performance of metallic substrate is inferior to that of ceramic one in condition of identical volume. The accumulated HC emission of the metallic one doubles that of ceramic one after 50 seconds. It is explained that the difference of LOT characteristic between metal and ceramic substrate as shown in Figure 26 and Table 6. As the metallic substrate has larger thermal mass, more energy was required to heat up the catalyst to the light-off temperature. To apply the metal substrate, more experiments considering the substrate design are required.

2.10. EHC (Wolf *et al.*, 1998; Bissett *et al.*, 1999a; Oh *et al.*, 1993a)

In view of the significant cold-start HC emission reduction potential of the electrically heated converter (EHC) technology demonstrated in this studies. Figure 28 shows that the test converter system was equipped with the EHC + LOC (Light-off catalyst). Two types of EHC, EHC-I (200 mΩ) and EHC-II (100 mΩ) were tested. Operating range of EHC was 120 seconds in the cold-start. Figure 29 shows that the temperature profiles of converters in the cold phase of FTP test. And times

Table 7. LOT characteristic of EHC.

Time (sec)	Inlet EHC	EHC-I (200 mΩ)	EHC-II (100 mΩ)
200°C	54	28	35
300°C	145	110	42
350°C	242	132	56

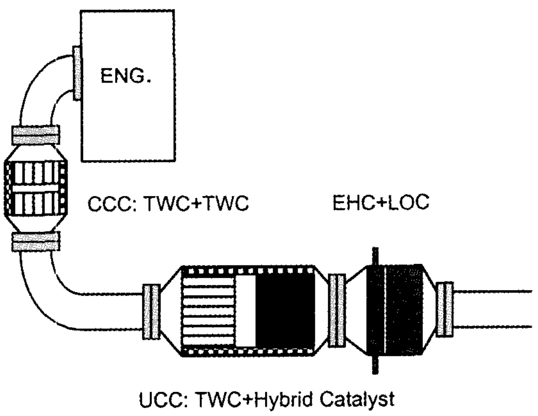


Figure 28. SULEV system with EHC.

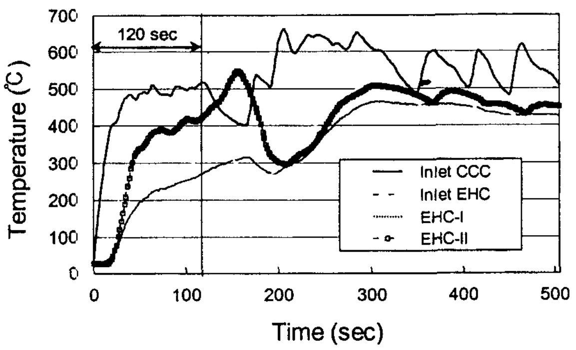


Figure 29. Temperature profiles of EHC.

required to reach some temperatures are summarized in Table 7.

In comparison with EHC-I and EHC-II showed that the times required to reach 300°C were 110 seconds and 42 seconds, respectively. This indicates that the EHC-II which has a resistance of 100 mΩ may have a better HC conversion efficiency at cold-start. As resistance of the electric heater is increased, the emission performance is decreased. Because the emission performance suffers from the slow heat-up rate caused by the large thermal mass. Computer simulations based on the EHC model developed previously show that although decreasing the volume of an electric heater generally improves the emission performance of EHC system.

2.11. Vehicle System for Gasoline SULEV Regulation (Masaki *et al.*, 1999; Hiroshi *et al.*, 1999)

The chief vehicle systems for gasoline SULEV represented by Figure 30 are as follows:

(1) For fuel supply, we replace the conventional fuel injector (SMD≒170 μm) with the air-shrouded fuel injector (SMD≒100 μm) so that the atomization characteristics of fuel become better, and fuel preparation during cold condition is improved.

(2) We shifted the conventional ignition timing into around TDC right after engine cranking, and ran the engine at the surrounding stoichiometric A/F with the

Table 8. Test vehicle spec.

Vehicle	Model	AVANTE
	Transmission	4-Speed A/T
Engine	Model	β -2.0
	Bore × Stroke	82.0 × 93.5 mm
	Displacement	1975 cc
	Compression Ratio	10.3 : 1
	Fuel Injector	Air-Shrouded
	Exh Manifold	Improved SUS

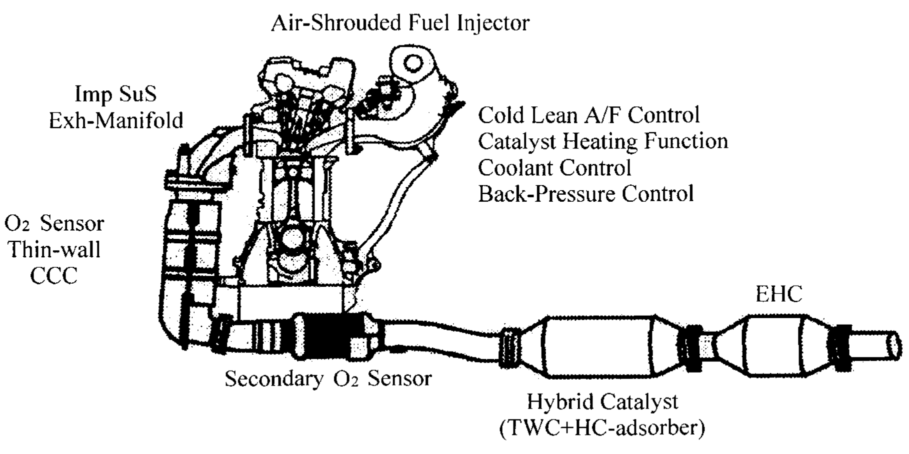


Figure 30. Exhaust system for gasoline SULEV regulations.

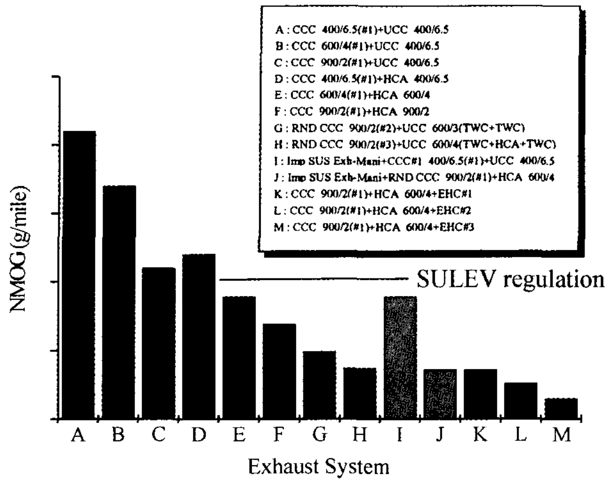


Figure 31. NMOG of exhaust system by types (LA-4: P1).

catalyst's heating function for the shortening of catalyst's LOT in the EMS logic.

(3) We substituted the Improved type of "SUS" materials' for LEV's type of "FCD-H" to improve exhaust gas flow and thermal mass. As a result, the conversion rate of exhaust gas goes up through the initial activation's shortening of catalyst and suppression of back-pressure's increase at the beginning of the cold period, as we strive for light weight.

(4) The CCC is loaded high as the thin-wall catalyst of Pd chain for the maximization of cold activation. The concept that absorbs emitted THC before the cold activation of CCC in the under-floor's position is adopted including the catalyst system (also known as Hybrid catalyst) that the function of HC-adsorber and TWC is for more effective elimination of adsorbed HC.

As a result of the vehicle test for gasoline SULEV regulations, we obtained the following findings:

Using LEV's system as the basis, the NMOG discharge level of the overall applications of the items in fresh condition (@0K) comply with gasoline SULEV regulations. The evaluation of all systems is requested in relation to the durability of each part along with the aging process.

3. CONCLUSION

The vehicle test result of the above-mentioned items is set the goal of efforts to develop a practical system. The following conclusion was reached based on the vehicle evaluation of practical use through the coolant control, fuel atomization for the reduction of engine raw emission, cold lean burn and the individual cylinder A/F precise control for the improvement of catalyst conversion efficiency, as well as the after-treatment such as thin-wall catalyst and HC-adsorber and EHC.

(1) The type of air-shrouding specially represents a high reduction rate on driving section between acceleration and deceleration.

(2) The fact that the low flow rate of the coolant (up to about 20%) has much reducing effect in exhaust gas is attributed to the cooling effect of the reduced circulation of the coolant.

(3) The THC decreased to 20% just after the cold lean operation by utilizing a port-throttling device.

(4) On the logic of P-I-D control, the P value in the engine driving condition is to determined, By such control, individual cylinder A/F control is well-controlled within 2%.

(5) Compared with the conventional exhaust manifold of FCD-H materials, all conditions with SUS materials and thickness yielded a reducing effect even though there is a difference in effect following the engine start (In case of starting A/F 13.6, the THC decreased to 12%, while A/F 14.5 yielded a reducing effect on THC by 27%).

(6) In THC reduction and LOT shortening of catalyst, the improvement effect of exhaust gas flow following shape modification is more critical than the reduction effect of thermal inertia according to the change in material and weight of the exhaust manifold (The type of the improved manifold as compared with the standard has brought the rise in temp of exhaust gas and CCC-center to about 50~100°C, while LOT shortening with FCD-H is 3 sec and SUS is 10 sec.).

(7) The thin-wall CCC yield a significant THC reduction effect (600/4: 23%↓, 900/2: 50%↓) compared to the standard type (400 cpsi/6.5 mil). Due to thin-wall cell thickness, LOT of CCC reduced to 5 sec, 9 sec at 600 cell and 900 cell, respectively. The center temp of the substrate bed, including the left and right sides, represents an equal distribution.

(8) The HC-adsorber is effective in reducing the initial peak HC emitted before the arrival of catalyst LOT. Through the improvement of catalytic agents in the HC-adsorber, the absorbing region of high temp explained more than 30°C and TWC characteristics improved.

(9) Following the improvement of adsorbing performance in high temp and TWC characteristics, we confirmed that HC-adsorber makes a significant contribution to the reduction of HC in cold start and evaluated the thermal durability of each HC-adsorbers with the aging process. Positive result was obtained in the improved HC-adsorber type.

(10) Afterwards, the optimization of catalyst volume and cell density into consideration in improving the canning method of the ceramic thin-wall substrate and drop in pressure.

(11) As the metallic substrate has larger thermal mass, more energy was required to heat up the catalyst to the light-off temperature. To apply the metal substrate, more experiments considering the substrate design are required.
(12) Using LEV's system as the basis, NMOG discharge of the overall application of the items in a fresh condition (@0K) complies with gasoline SULEV regulations, but an evaluation of the complete system is required.

NOMENCLATURE

BD	: Bulk Density
CARB	: California Air Resources Board
GSA	: Geometric Surface Area
LA4	: Los Angels 4-Mode Test
LOT	: Light-Off Temperature
NMOG	: Non-Methane Organic Gas
OFA	: Open Frontal Area
SMD	: Sauter Mean Diameter
ULEV	: Ultra Low Emission Vehicle
ZEV	: Zero Emission Vehicle

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