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CHANGE OF CATALYST TEMPERATURE WITH UEGI TECHNOLOGY DURING COLD START

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ABSTRACT–Most of the pollutants from passenger cars are emitted during the cold-transient phase of the FTP-75 test. In order to reduce the exhaust emissions during the cold-transient period, it is essential to warm up the catalyst as fast as possible after the engine starts, and the Unburned Exhaust Gas Ignition (UEGI) technology was developed through our previous studies to help close-coupled catalytic converters (CCC) reach the light-off temperature within a few seconds after cold-start. The UEGI system operates by igniting the unburned exhaust mixture by glow plugs installed upstream of the catalyst. The flame generates a high amount of heat, and if the heat is concentrated on a specific area of monolith surface, then thermal crack or failure of the monolith could occur. Therefore, it is very important to monitor the temperature distribution in the CCC during the UEGI operation, so the local temperatures in the monolith were measured using thermocouples. Experimental results showed that the temperature of CCC rises faster with the UEGI technology, and the CCC reaches the light-off temperature earlier than the baseline case. Under the conditions tested, the light-off time of the baseline case was 62 seconds, compared with 33 seconds for the UEGI case. The peak temperature is well under the thermal melting condition, and temperature distribution is not so severe as to consider thermal stress. It is noted that the UEGI technology is an effective method to warm up the catalyst with a small amount of thermal stress during the cold start period.

KEY WORDS : Unburned exhaust gas ignition (UEGI), Close-coupled catalytic converter (CCC), Light-off temperature, Exhaust emissions, Cold start

1. INTRODUCTION

Although the recent development of automobile industies has been contributing to the enhancement of national economic growth, exhaust emissions due to the increase of automobiles are also given back to us as air-pollution problems. Especially, carbon monoxide (CO), thermal hydrocarbon (THCs), and nitrogen oxides (NOx) from gasoline-fueled vehicles cause serious environmental pollution. Accordingly, the worldwide exhaust emission regulations are getting more stringent, and consequently, researches to decrease automotive emissions have been intensively carried out.

In order to meet the stringent automotive emission regulations, we should either enhance the efficiency of combustion or apply after-treatment systems. However, satisfying emission standards by modifying the previous combustion system of an engine is generally difficult, and even if possible, its performance would be decreased. One way to solve this problem is the after-treatment method to achieve purification by the chemical reactions of the pollutants using catalyst in the exhaust system, without particular changes of combustion chamber.

Three-way catalytic converter which is widely used in gasoline engine helps the chemical reactions among CO, HC, and NOx which are harmful chemicals released in exhaust gas and converts to N_2, CO_2, and H_2O which are not harmful molecules simultaneously.

Generally, the conversion efficiency of catalyst largely depends on temperature, and the efficiency is extremely low until the catalyst reaches light-off temperature of 250–350°C. But it shows drastically strong chemical conversion beyond the light-off temperature. Therefore, during cold start such as a cold transient period of FTP-75, the amount of pollutant emissions is very high, about 80% of the total emissions of the mode test. Accordingly, reduction of cold-start emission in a vehicle is crucial. Various ideas and solutions have been suggested to reduce the cold-start emission and the ideas include hydrocarbon adsorber and catalysts (Lee *et al.*, 2004).

In addition, faster increase of temperature is also crucial, and as a method of faster warmup, there is close-coupled catalytic converter that uses the heat of exhaust gas effectively to raise the catalyst temperature with the

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Corresponding author. e-mail: yscho@kookmin.ac.kr catalyst attached very close to the exhaust manifold.

Close-coupled catalytic converter (CCC) is directly attached to the exhaust manifold, so exhaust gas may be concentrated in specific area of monolith. It may cause various problems such as partial failure or local thermal melting of catalytic monolith and it is reported that the design of exhaust manifold is crucial to distribute the hot exhaust gas uniform (Lee *et al.*, 1998).

For fast warmup of catalyst, the Unburned Exhaust Gas Ignition (UEGI) which modifies the EGI (Exhaust Gas Ignition) has been developed through our previous studies (Eade *et al.*, 1995; Cho *et al.*, 2000; Kim *et al.*, 2003). But the combinations of the two ideas may or may not cause unexpected thermal problems on catalytic monolith.

In this study, spatial distribution and increase of temperature in the time domain are investigated by measuring local temperatures in the monolith, in order to see the effects of temperature rise and distribution to the CCC with the UEGI technology.

2. CONCEPT OF UEGI

EGI has been recognized for its contribution to the reduction of harmful exhaust emissions. However, for a few seconds after a cold start, excessively rich air-fuel mixture supplied to the engine may cause deposits which results in the increase of HC emission in the combustion chamber.

During the cold start, the UEGI system interrupts ignition signals of the cylinder #1 and #4, and then the two cylinders act as fuel-air supply pump for UEGI. Glow plugs installed in the exhaust manifold ignite the unburned mixtures coming from the two misfired cylinders at the entrance of the catalytic converter, and heat generated due to the combustion helps the warmup of the catalytic converter directly, forcing it to reach the light-off temperature faster.

The UEGI can solve the deposit problems of engines that the EGI might have. It is also cost-effective. It only uses glow plugs not any particular additional devices such as secondary air supply devices. Also, after an engine starts, the CCC reaches the light-off temperature within several seconds, so pre-heating of the catalyst is very effective during the cold start period.

However, UEGI combustion does not take place in a combustion chamber. Thus misfire in exhaust manifold would occur if the locations of the glow plugs are improperly selected. Such misfire results in the increase of unburned hydrocarbon which provides CCC with an abnormal chemical reaction. So it is crucial that the position of glow plugs should be carefully determined. In the preliminary tests of UEGI the glow plug locations are suggested. Figure 1 shows the exhaust manifold with glow plugs installed for UEGI operation.

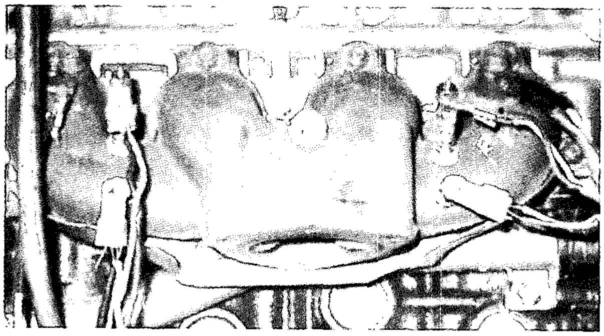


Figure 1. Exhaust manifold of UEGI system.

3. APPARATUS

3.1. Test Engine

In this experiment, a 1975 cc, 16-valve PFI (Port Fuel Injection) engine was used. Before each tests, the engine is soaked at least 12 hours so that the temperature of the engine is maintained between 26 and 29°C to simulate the cold start conditions. The following additional devices are mounted to the engine to operate UEGI and measure the related data.

3.2. Catalyst

Catalyst used for this study has 6.5×10^{-3} inch wall thickness and 400 cpsi (cells per square inch) cell density. Total volume of the catalyst is one liter which consists of 0.4 liter for the front brick, and 0.6 liter for the rear one.

3.3. Exhaust Manifold

An exhaust manifold with two separation walls is applied to prevent unburned air-fuel mixture from being mixed with the burned exhaust gas coming out of the other two cylinders, before the unburned mixture is ignited by the glow plugs. The separation walls are located between no.1 and no. 4 runners, and no. 2 and no. 3 runners.

3.4. Data Acquisition System

In order to deal with the spatial temperature distribution, many signals of thermocouples should be effectively investigated and stored. At first, the k-type thermocouples are applied to measure the monolith temperature distributions. The measured data should be synchronized with engine operational history. For the study, the signal management and storing system are designed using LabVIEW. The system collects 200 samples a second from each thermocouple channel, stores the data every 0.5 second, and refreshes the buffer. Engine operation parameters such as engine speed are scanned and monitored every second, synchronous with temperature data.

4. EXPERIMENTS

4.1. UEGI Experimental Approach

After letting air-fuel mixture from the intentionally misfired cylinder #1 and #4 pass through exhaust manifold for 10 seconds after cranking, the mixture is burned in the upstream of CCC by the glow plugs installed in the exhaust manifold. At this time, engine runs idle through the normal operation in the other two cylinders.

After 10 seconds, glow plugs which are the ignition sources of UEGI are removed and the ignition signals of all cylinders become on duty. At this time, UEGI controls air/fuel ratio lean than the stoichiometric ratio using MOTEC M8 ECU, allowing the temperature to increase effectively by helping the reaction of catalyst heated by UEGI (Drake *et al.*, 1996). Figure 2 shows flame ignited by the exhaust manifold of the engine with UEGI system using glow plugs.

4.2. Temperature Measurement

Two cases, baseline and UEGI are tested to measure monolith temperature. In order to measure spatial temperature distribution of the monolith, the rear brick of CCC was cut out and the thermocouples were inserted from the downstream of the front brick of CCC. Since the thermocouple was inserted from the downstream to the upstream after removing the rear part of the monolith, the thermocouples are easily allocated in the monolith. Furthermore a guide installed on CCC prevents vibration of thermocouples due to the engine operation. As a result, stable measurements of temperature were possible.

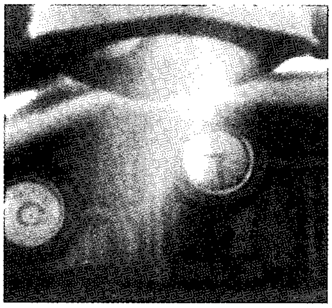


Figure 2. UEGI flame using glow plugs.

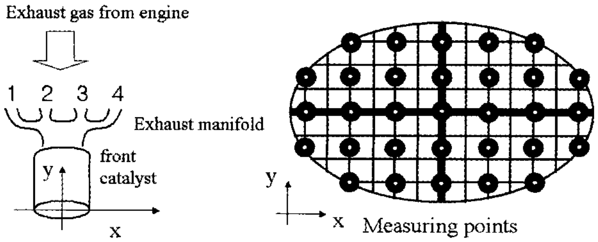


Figure 3. Temperature Measuring Points of the CCC.

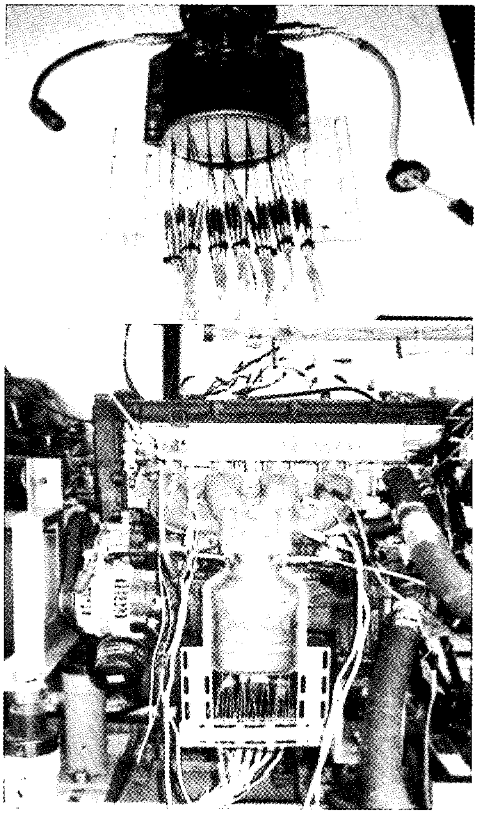
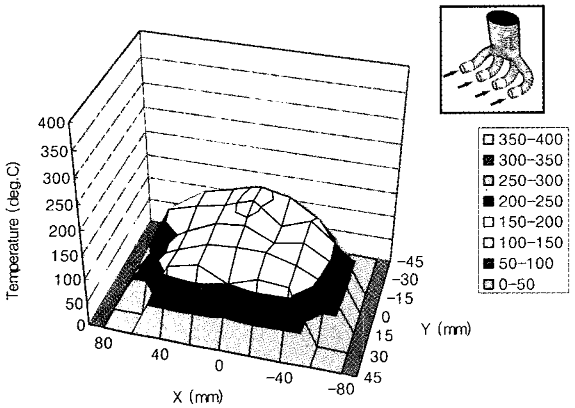


Figure 4. Thermocouples mounted in the CCC.

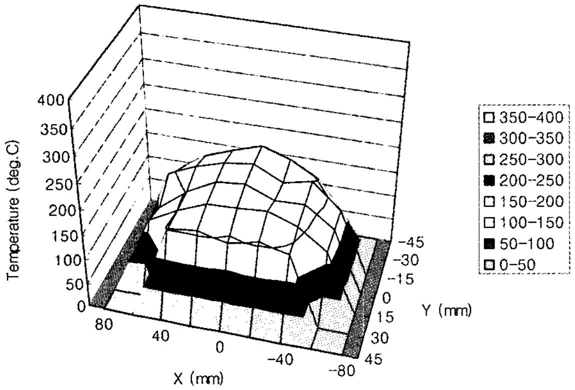
Temperature distribution was measured at the surface of the first monolith and 20 mm below the surface. For the measurement of spatial distribution, 31 thermocouples are inserted in the same longitudinal position. Figure 3 shows the location of measurement of the thermocouple seen from the upstream of the catalyst. Since it is anticipated that temperature distribution of the catalyst has stronger symmetry in long axis than short axis, the locations of measurement were set so that the interval of the short axis is dense. Surface temperature of monolith was measured in the 2 mm depth from the surface to avoid direct heat transfer from exhaust. Figure 4 shows that the thermocouple is installed in the carrier.

5. RESULTS AND DISCUSSION

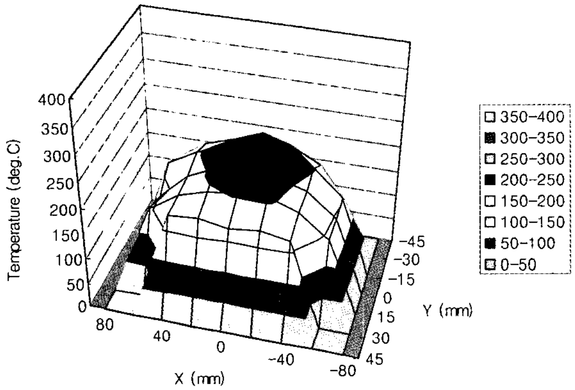
Figure 5 and Figure 6 are the result of the experiment in which UEGI is not applied, and Figure 7 and Figure 8 show temperature distributions when UEGI is applied. These graphs show the surface of the catalyst upstream and temperature measured at 20 mm. The distributions of catalyst temperature correspond to the figure shown in the pictures of catalyst geometry inserted on the upper



(a) Face temperature distribution at 10 sec.

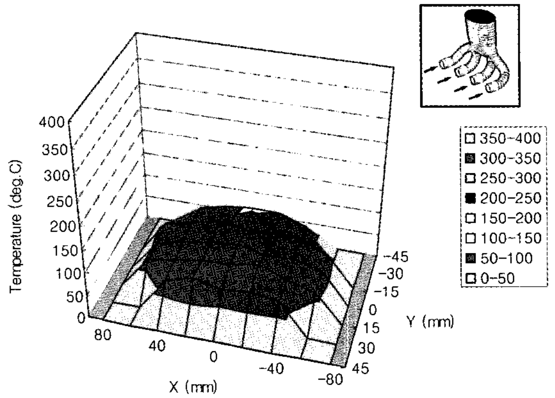


(b) Face temperature distribution at 20 sec.

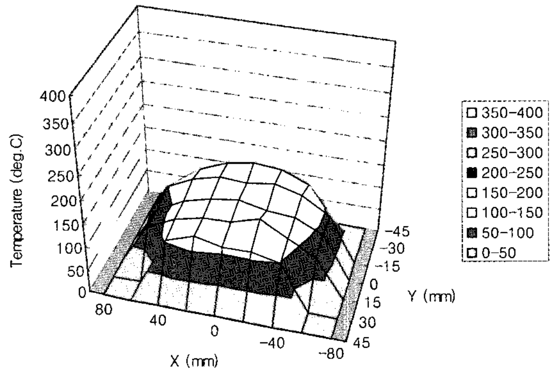


(c) Face temperature distribution at 30 sec.

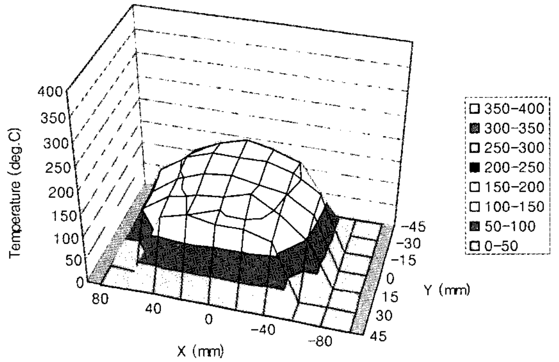
Figure 5. Monolith temperature distribution of baseline case (2 mm downstream).



(a) 20mm downstream temperature distribution at 10 sec.



(b) 20mm downstream temperature distribution at 20 sec.



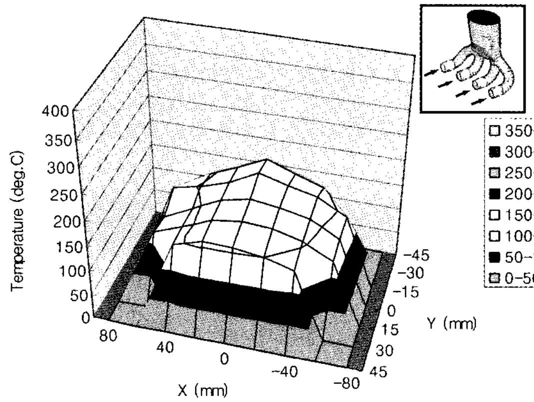
(c) 20mm downstream temperature distribution at 30 sec.

Figure 6. Monolith temperature distribution of baseline case (20 mm downstream).

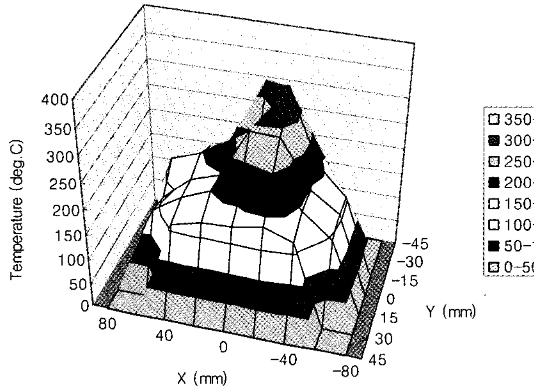
right side of each figure.

As shown in the graph, the highest temperature is located on outer region of catalyst, due to the geometry of exhaust manifold. It is understood that the flow distribution of a CCC is dependent on the shape of exhaust manifold (Kim *et al.*, 2004), because the light between exhaust manifold and catalyst is not as long as for the flow distribution to be fully developed. It is also shown that the average temperature of the monolith increases due to UEGI.

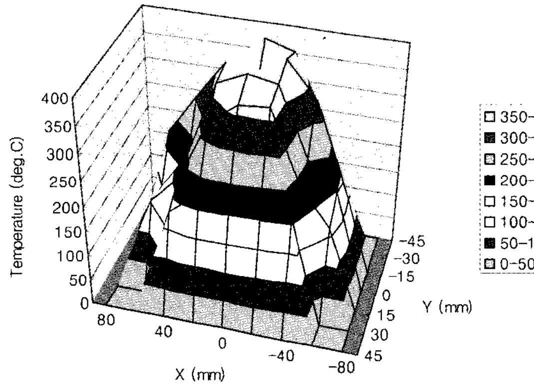
Comparing Figure 5(a) and Figure 7(a), when the initial 10 seconds of UEGI operation is completed,



(a) Face temperature distribution at 10 sec.

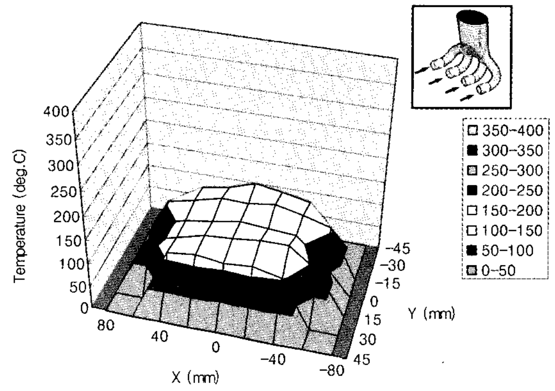


(b) Face temperature distribution at 20 sec.

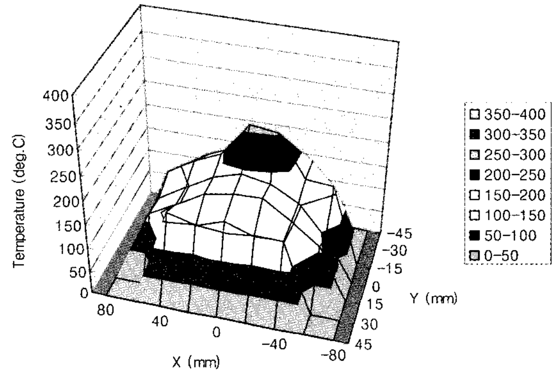


(c) Face temperature distribution at 30 sec.

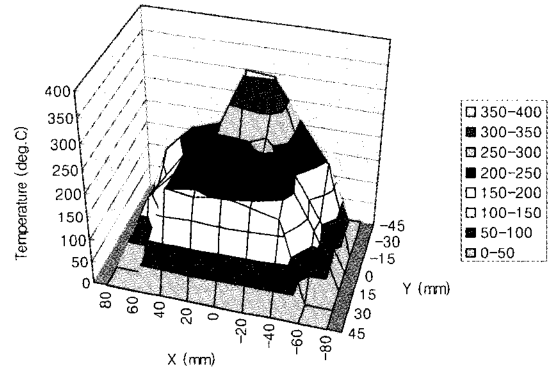
Figure 7. Monolith temperature distribution of UEGI case (2 mm downstream).



(a) 20mm downstream temperature distribution at 10 sec.



(b) 20mm downstream temperature distribution at 20 sec.



(c) 20mm downstream temperature distribution at 30 sec.

Figure 8. Monolith temperature distribution of UEGI case (20 mm downstream).

catalyst temperature in the case of UEGI tends to be considerably higher than that of the baseline case. Maximum temperature of UEGI shows 37°C increase of catalyst temperature. Afterwards, the engine is controlled lean air/fuel ratio by the MOTEC. Through the control, temperature increases more rapidly due to the activation of the oxidation reaction in the heated catalyst. Those two cylinders that emit unburned gas begin to emit burned gas, so the temperature rise due to both oxidation reaction of the catalyst by lean exhaust gas and the combustion of the cylinder becomes obvious.

As shown in Figure 5(b) and Figure 7(b), the temperature difference, 46°C average and 156°C maximum, occurred at 20 seconds after engine start. It is considered the catalyst heated by UEGI reaches near the light-off temperature faster compared to baseline case resulting in early start of oxidation reaction at the front of catalyst.

Figure 6 and Figure 8 show the results measured at the 20 mm distance from the surface of the catalyst. Due to the heat transfer from the catalyst surface, quantitative temperature becomes lower, but the distributions are similar to Figure 5 and Figure 7. It is also noticed that the spatial temperature gradient becomes lower compared with the surface temperature distribution due to the isotropic heat transfer in the catalytic monolith.

Experimental result shows that the catalyst surface is heated by the flame generated by the initial UEGI, and catalyst oxidation reaction resulting from fast increase of temperature by UEGI allows higher temperature distribution near the center. Other catalyst region reaches light-off temperature by the heat obtained from exhaust gas and heat transfer from center. As UEGI helps the fast catalyst oxidation, overall temperature of catalyst also shows fast increase. Figure 9 shows the comparison of exhaust gas and CCC temperature between baseline and UEGI. CCC temperature is measured in the center of catalyst. In the figure, it is clearly shown that exhaust gas and catalyst temperature increase when UEGI is applied. After 30 seconds of UEGI case, it is observed that the catalyst temperature becomes higher than exhaust gas temperature. It means that a new source of heat release is generated in the catalyst and the crossover between exhaust gas and catalyst temperature curve indicates that the catalyst becomes activated. Such crossover point occurs at 90 seconds in the baseline case. Therefore it can be good evidence that the UEGI helps the start of catalytic oxidation and fast light-off.

All temperature values obtained from the experiment were below 400°C which is far below the thermal melting temperature of the catalyst. Furthermore, from Figure 9, maximum gradient of temperature in time domain is 72.6 /sec and 6/mm in spatial domain. It is reasonable to conclude that the UEGI hardly has problems regarding thermal melting or thermal stress.

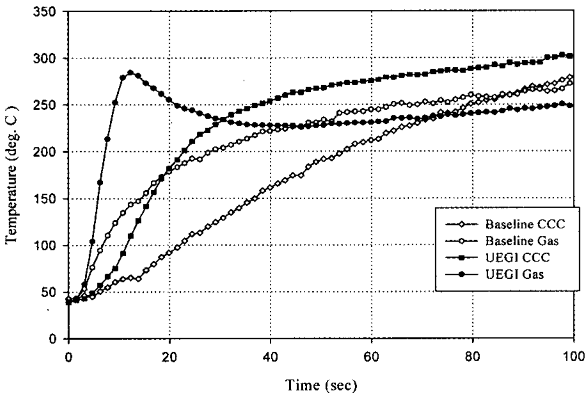


Figure 9. Comparison of exhaust gas and CCC temperatures between baseline and UEGI cases.

The temperature of exhaust gas while UEGI is activated was about 50°C higher than that of the baseline case. Measurements of exhaust gas temperature were done at the location where the unburned gas is ignited by the glow plug and exhaust gas from the two firing cylinders are mixed. As introduced above in this article, two cylinders exhaust unburned gas, and the other two cylinders exhaust burned gas while UEGI is activated. Also, the heat generated by UEGI heats the exhaust manifold faster, reducing the heat loss from the exhaust gas to the exhaust manifold. As a result of complex effect of these causes, the exhaust gas temperature in the case of UEGI is higher than that of the other way around.

In the case of baseline, it took about 62 seconds for the temperature of the center of the catalyst located in the 20 mm downstream from the catalyst surface to be 250°C, whereas about 33 seconds in the case of UEGI.

These values were obtained from the experimental device where the rear section of the catalyst was removed, so if measurement is done in the ordinary exhaust system, the heat loss to the atmosphere will decrease, resulting in higher temperature. Furthermore in the present article, the engine was in idle condition, but FTP-75 Mode reaches acceleration region 30 seconds after initial cold start, so it is anticipated that the activation of the catalyst is faster in the actual automobile application tests when UEGI is applied.

6. CONCLUSION

UEGI technology helps catalyst reach the light-off temperature faster during the cold start period, and it is anticipated that a significant amount of pollutant exhaust emission can be reduced. From the present experiment, it was observed that, in the case of UEGI, the time taken for the temperature measured at 20 mm from the face of the monolith, to reach 250°C was about 30 seconds shorter than when UEGI was not applied to the engine (33 seconds vs. 62 seconds, respectively).

In this study, it was confirmed from the experiment that the catalyst temperature raised by UEGI during the cold start period is far below the temperature that would cause thermal crack or melting. The non-uniform temperature distribution of the surface becomes stabilized steadily, resulting in the decrease of thermal stress.

It is also investigated that the shape of exhaust manifold affects the temperature distribution of CCC. Therefore, in order to maximize the performance of UEGI, exhaust manifold geometry as well as the positions of glow plugs should be optimized.

It is anticipated that if combustion stability and accurate and precise air-fuel ratio control are achieved during cold start, the increase of catalyst temperature and fast light-off through UEGI will be realized.

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REFERENCES

Cho, Y. S., Lee, Y. S., Kim, C. S., Choi, J. W. and Cheon, J. Y. (2000). A study of catalyst temperature control by using UEGI technology. Spring Conference Proc. *Korean Society of Automotive Engineering*, 19–24.

Drake, M. C., Sinkevitch, R. M., Quader, A. A., Olson, K. L. and Chapaton, T. J. (1996). Effect of fuel/air ratio variations on catalyst performance and hydrocarbon emissions during cold-start and warm-up. *SAE Paper No.* 962075.

Eade, D., Hurley, R. G., Rutter, B., Inman, G. and Bakshi, R. (1995). Fast light-off of underbody catalysts using exhaust gasIgnition (EGI), *SAE Paper No.* 952417.

Kim, D. S., Kang, B. G., Yang, C. S. and Cho, Y. S. (2003). Emission reduction using unburned exhaust gas ignition. *Trans. Korean Society of Automotive Engineers* **11**, **3**, 39–47.

Kim, D. S. and Cho, Y. S. (2004). LDV measurement, flow visualization and numerical analysis of flow distribution in a close-coupled catalytic converter. *KSME International Journal* **18**, **11**, 2032–2041.

Lee, S. C., Jang, J. H., Lee, B. Y., Bae, J. H. and Choung, S. J. (2004). HCA and TWC hybrid system for reducing cold-start emission. *Int. J. Automotive Technology* **5**, **1**, 1–7.

Lee, K. S., Bai, L., Zhao, F.-Q., Liu, Y. and Lai, M.-C. (1998). Transient flow and pressure characteristics inside a closed-coupled catalytic converter. *SAE Paper No.* 982548.