Test Procedure on Exhaust Gas Entering into Vehicle Cabin

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Korea Transportation Safety Authority
Korea Automobile Testing & Research Institute
Contents

1. Defect Investigation in 2011

Background

- Consumer complaints “Exhaust Odor / Exhaust gas entering into vehicle cabin”
  - Exhaust smell can disturb driving and raises safety concerns
  - Total 318 complaint cases in 2011
    - Website: 158 cases, telephone: 20 cases, Korea Consumer Affairs Institute: 140 cases
- Ministry of Land, Infrastructure and Transport had launched an investigation into this issue

<KBS news regarding “exhaust gas entering into vehicle cabin”>
Test Mode based on consumer complaints

- Test mode to see if the CO gas was entering into cabin while driving

  - Test mode configuration with high speed and acceleration / deceleration
  - HVAC setting in recirculation mode, sunroof tilt open / closed

Test mode in 2011

Total 6 cycles approx. 82km driving, 32 min

< Test mode used in defect investigation in 2011 >
Vehicle testing

- Testing devices and vehicle testing in proving ground

- Measuring point: Head position of driver and passenger seat, center position of trunk

Test Device: Testo 330 LL
- CO Low Range: 0~500 ppm
- Resolution: 0.1 ppm
- Accuracy: ±2 ppm (0.0~39.9 ppm), Other range ± 5%
Testing Results

✓ Vehicle testing results using the test mode in 2011

• CO concentration increases gradually in trunk area (10~14 ppm)

• CO was detected in vehicle cabin at the left and right seat position (2~4 ppm)
Testing Results

Vehicle testing result using the constant speed test

- CO concentration increases gradually depending on vehicle speed
- CO was detected in high speed more than 140 km/h

<table>
<thead>
<tr>
<th>Speed</th>
<th>CO concentration (unit : ppm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cabin</td>
<td>Trunk</td>
</tr>
<tr>
<td>60 km/h</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>80 km/h</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>100 km/h</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>120 km/h</td>
<td>1.8</td>
<td>4.2</td>
</tr>
<tr>
<td>140 km/h</td>
<td>4.3</td>
<td>31.7</td>
</tr>
<tr>
<td>160 km/h</td>
<td>11.3</td>
<td>35.4</td>
</tr>
</tbody>
</table>
Testing Results

- Vehicle testing results in 18 test vehicles

- CO was detected in several cars in vehicle cabin and trunk

<table>
<thead>
<tr>
<th>Test Vehicle</th>
<th>CO concentration in cabin (unit : ppm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cabin</td>
<td>Trunk</td>
</tr>
<tr>
<td>A</td>
<td>70.7</td>
<td>81</td>
</tr>
<tr>
<td>B</td>
<td>25.4</td>
<td>60</td>
</tr>
<tr>
<td>C</td>
<td>21</td>
<td>72</td>
</tr>
<tr>
<td>D</td>
<td>17.9</td>
<td>61</td>
</tr>
<tr>
<td>E</td>
<td>15.9</td>
<td>71</td>
</tr>
<tr>
<td>F</td>
<td>9.8</td>
<td>9</td>
</tr>
<tr>
<td>G</td>
<td>7.3</td>
<td>53</td>
</tr>
<tr>
<td>H</td>
<td>5.7</td>
<td>29</td>
</tr>
<tr>
<td>I</td>
<td>4.1</td>
<td>23</td>
</tr>
<tr>
<td>J</td>
<td>2.5</td>
<td>18</td>
</tr>
<tr>
<td>K</td>
<td>2.4</td>
<td>9</td>
</tr>
<tr>
<td>L</td>
<td>2.2</td>
<td>18</td>
</tr>
<tr>
<td>M</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>N</td>
<td>1.8</td>
<td>9</td>
</tr>
<tr>
<td>O</td>
<td>1.4</td>
<td>54</td>
</tr>
<tr>
<td>P</td>
<td>1.1</td>
<td>10</td>
</tr>
<tr>
<td>Q</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>R</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>
Defect Investigation conclusions

- Ministry of Land, Infrastructure and Transport had launched an investigation into this issue
  - Possible leakage of exhaust fumes and exposure to carbon monoxide inside the vehicle
  - 49 vehicles were tested in the defect Investigation in 2011
  - MOLIT recommend the free repair services to consumer regarding 3 vehicle models

Future works

- Need to develop management standards including test procedures, test mode, harmful substance and limits to prevent future cases
  - Develop the test mode taking into account cause and effect of exhaust gas incursions
  - Exhaust gases should not be entering into cabin
  - Other gases and harmful substances should be considered when testing for CO and exhaust odors leaking into the cabin
  - Determine the harmful substances and limits
1. Defect Investigation in 2011
Issue Summary

- **Development of Test Procedure in 2013-2015**
  - How could the exhaust gas enter into vehicle cabins
  - Exhaust gas inflow into vehicle cabin and the rear of vehicles using CFD
  - Exhaust gas sources from vehicle tail pipe
  - Which driving conditions most likely to cause exhaust to enter into cabin
  - Review existing test procedures, and collect similar cases
  - Testing in chassis dynamometers, proving grounds and real roads with various conditions
  - Develop test procedures taking into account causes and effects on exhaust gas incursions
  - Consideration of CO gases as well as other exhaust gases regarding exhaust odors
  - Determine the harmful substances and limit values
How could the exhaust gas enter into vehicle cabins?

- When cars pick up speed with the air conditioning system on recirculation mode, exhaust gases could enter the passenger compartment due to pressure difference in cabin and vortex flow in rear part of the vehicle.
  - High acceleration or wide open throttle (WOT) with recirculation mode HAVC setting
  - Very high speed driving on highway (more than 140 km/h)
  - In some circumstances, hatch door sealing problems, air extractor design, sunroof tilt open is a major factor in leakage into the cabin
- Warning in vehicle owner’s manual: The boot lid must always be completely closed when the vehicle is moving, otherwise exhaust fumes can be drawn into the interior

<table>
<thead>
<tr>
<th>Display messages</th>
<th>Possible causes/consequences and Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Icon]</td>
<td>Sedan: the trunk lid is open.</td>
</tr>
<tr>
<td></td>
<td>▶ Close the trunk lid.</td>
</tr>
<tr>
<td>![Icon]</td>
<td>Wagon: the tailgate is open.</td>
</tr>
<tr>
<td></td>
<td>▶ WARNING</td>
</tr>
<tr>
<td></td>
<td>When the engine is running, exhaust gases can enter the vehicle interior if the tailgate is open.</td>
</tr>
<tr>
<td></td>
<td>There is a risk of poisoning.</td>
</tr>
<tr>
<td></td>
<td>▶ Close the tailgate.</td>
</tr>
</tbody>
</table>

![Image of warning sign]
**Computational Fluid Dynamics (CFD)**

- Simulation for exhaust gases entering into cabin using the CFD method

- The vortex flow occurs in the back part of sedan vehicles depending on vehicle speed

*Source: Fundamentals of Vehicle Dynamics, Thomas D. Gillespie*
Computational Fluid Dynamics (CFD)

✓ Simulation for exhaust gases entering into cabin using the CFD method
Test on exhaust gases on chassis dynamometer

- Exhaust sources and measurements on Emission test mode

- Carbon monoxide occurring from high speed (over 140 km/h) and high acceleration (WOT)

![Chassis dynamometer](image1.png) ![Exhaust gas analyzer](image2.png)

![Test result of carbon monoxide in vehicle speed on gasoline vehicle](chart1.png) ![Test result of carbon monoxide depending on acceleration rate on gasoline vehicle](chart2.png)
Test results on exhaust gases on chassis dynamometer

Gasoline Vehicle, exhaust gas sources from vehicle tail pipe

- Substance concentration values estimated by dilution factor (Unit : ppm)

<table>
<thead>
<tr>
<th>Average Speed</th>
<th>THC</th>
<th>NOx</th>
<th>CO</th>
<th>Benzene</th>
<th>Toluene</th>
<th>Ethyl benzene</th>
<th>m-p- Xylene</th>
<th>o-Xylene</th>
<th>Styrene</th>
<th>1,3,5-Trimethylbenzene</th>
<th>1,2,4-Trimethylbenzene</th>
<th>Formaldehyde</th>
<th>Acetaldehyde</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 km/h</td>
<td>73.044</td>
<td>0.811</td>
<td>8434.749</td>
<td>0.522</td>
<td>0.323</td>
<td>0.025</td>
<td>0.069</td>
<td>0.052</td>
<td>0.029</td>
<td>0.012</td>
<td>0.047</td>
<td>0.009</td>
<td>0.020</td>
</tr>
<tr>
<td>34 km/h</td>
<td>5.210</td>
<td>2.480</td>
<td>87.105</td>
<td>0.004</td>
<td>0.122</td>
<td>0.003</td>
<td>0.003</td>
<td>0.000</td>
<td>0.001</td>
<td>0.001</td>
<td>0.021</td>
<td>0.009</td>
<td>0.063</td>
</tr>
<tr>
<td>4.7 km/h</td>
<td>6.565</td>
<td>0.471</td>
<td>163.567</td>
<td>0.098</td>
<td>0.863</td>
<td>0.034</td>
<td>0.066</td>
<td>0.065</td>
<td>0.001</td>
<td>0.001</td>
<td>0.034</td>
<td>0.009</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Diesel Vehicle, exhaust gas sources from vehicle tail pipe

- Substance concentration values estimated by dilution factor (Unit : ppm)

<table>
<thead>
<tr>
<th>Average Speed</th>
<th>THC</th>
<th>NOx</th>
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<th>1,2,4-Trimethylbenzene</th>
<th>Formaldehyde</th>
<th>Acetaldehyde</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 km/h</td>
<td>6.355</td>
<td>1359.254</td>
<td>14.069</td>
<td>0.021</td>
<td>0.012</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.007</td>
<td>0.002</td>
<td>0.000</td>
<td>0.042</td>
<td>0.152</td>
</tr>
<tr>
<td>34 km/h</td>
<td>24.886</td>
<td>331.447</td>
<td>18.463</td>
<td>0.023</td>
<td>0.102</td>
<td>0.002</td>
<td>0.002</td>
<td>0.000</td>
<td>0.022</td>
<td>0.002</td>
<td>0.022</td>
<td>0.158</td>
<td>0.204</td>
</tr>
<tr>
<td>4.7 km/h</td>
<td>72.393</td>
<td>190.197</td>
<td>2.519</td>
<td>0.170</td>
<td>0.097</td>
<td>0.002</td>
<td>0.044</td>
<td>0.002</td>
<td>0.000</td>
<td>0.002</td>
<td>0.042</td>
<td>1.102</td>
<td>0.000</td>
</tr>
</tbody>
</table>
New Test mode for exhaust gases entering into cabin in 2016

- Idling mode, (basic conditions)
  - Engine idling in normal condition

- Cruising speed driving mode, (normal conditions)
  - 80 ± 5 km/h, 100 ± 5 km/h, 120 ± 5 km/h, 140 ± 5 km/h

- Acceleration mode, (worst-case conditions)
  - Accelerate vehicles from 65 km/h to 130 km/h, followed by an immediate coast-down (deceleration) to 65 km/h, then cruise drive 500 meters, repeat for 8 cycles

- Real-road driving mode
  - Real-road driving mode with/without acceleration as traffic required
Proving Ground Test

- Proving ground driving test
  - Idling conditions, cruising speed conditions, acceleration conditions
- Test vehicle: Gasoline vehicle, 3,000 cc, sedan
- Measurement devices setting position:
  - Nose position of front seat, back seat
  - Center position of truck
  - Rear of vehicle
Gas and Speed Measuring Devices

- Test Device: Vbox mini
  - Speed Range: 0.1 ~ 1,609 km/h
  - Resolution: 0.1 km/h
  - Accuracy: 0.2 km/h
- Test Device: Testo 330 LL
  - CO Range: 0~500 ppm
  - Resolution: 0.1 ppm
  - Accuracy: ±2 pm (0.0 ~ 39.9 ppm), Other range ± 5%
- Test Device: Testo 350K
  - NO Range: 0~300 ppm
  - Resolution: 0.1 ppm
  - Accuracy: ±2 pm (0.0 ~ 39.9 ppm), Other range ± 5%
  - NO2 Range: 0~500 ppm
  - Resolution: 0.1 ppm
  - Accuracy: ±5 pm (0.0 ~ 39.9 ppm), Other range ± 5%
Idling mode test

- Engine idling in normal conditions, not moving
- Total test time: 10 min
  - Stabilizing time: 5 min, Measuring time: 5 min
- CO was detected in the rear hatch, but not detected in cabins
Cruising speed driving mode

- Cruising speed driving mode, (normal conditions)
  - 80 ± 5 km/h, 100 ± 5 km/h, 120 ± 5 km/h, 140 ± 5 km/h
  - Each test time in stated speed: 5 min
  - If CO is detected in test speed, test again in that speed for 20 min duration
  - CO was detected in 140 km/h,
Proving Ground Test

- Cruising speed driving mode

  ✓ Cruising speed driving mode

  • 140 ± 5 km/h

  • Total test time: 20 min (stabilizing time 10 min, measuring time 10 min)

  • CO was detected in cabin with 140 km/h (8 ~ 9 ppm)
Ø Acceleration mode

✓ Acceleration mode, (worst-case conditions)

• Accelerate vehicles from 65 km/h to 130km/h, followed by an immediate coast-down (deceleration) to 65 km/h, then cruise drive 500 meters, repeat for 8 cycles

• Total 8 cycle (4 stabilizing cycle, 4 measuring cycle)
Acceleration mode

- Acceleration mode, (worst-case conditions)
  - When accelerating, high concentration of CO was detected in rear area (max 3,000 ppm)
  - When accelerating, CO entered into the trunk zone through the rear hatch (max 100 ppm)
  - CO concentration was increased gradually from 40 ppm to 80 ppm in the cabin
Real-road Driving test

- Real-road driving mode
  - Real-road driving test in same course with/without acceleration (2 mode)
  - Driving course: 45 km (mostly of highway road)
  - Average vehicle speed: approx. 80 km/h
  - Driving time: approx. 40 min

<KATRI -> Songtan IC>  <Songtan IC -> KATRI>
Real-road Driving Test

- Real-road Driving test
  - Real-road driving mode (careful driving)
    - Real-road driving test in the same course without acceleration
    - Smooth driving, Throttle open not more than 50%
    - CO was not detected in cabin
Real-road Driving Test

- **Real-road Driving test**
  - Real-road driving mode (overtaking driving as traffic required)
    - Real-road driving test in same course with acceleration (near WOT)
    - Overtaking driving depending on road traffic as traffic required
    - CO was detected in cabin 20 ~ 35 ppm, in response to acceleration
    - Car acceleration: 11 times over 35 minutes
Test results

- CO gas enters into cabin in response to acceleration or high speed driving, especially for overtaking driving on highway, with HVAC in recirculation mode.
- After repair, CO gas was not detected in most test modes, except acceleration mode with sunroof tilt open.
- Hatch door sealing problems, air extractor design, sunroof tilt open, and tail pipe position may affect exhaust leaks into cabin.

<table>
<thead>
<tr>
<th>Test results for CO gas incursion</th>
<th>Before repair</th>
<th>After repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunroof</td>
<td>closed</td>
<td>tilt open</td>
</tr>
<tr>
<td>Idle mode</td>
<td>N.D.</td>
<td>-</td>
</tr>
<tr>
<td>Cruising mode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>100</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>120</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>140</td>
<td>8~9 ppm</td>
<td>0~3 ppm</td>
</tr>
<tr>
<td>Acceleration mode</td>
<td>40~80 ppm</td>
<td>30~35 ppm</td>
</tr>
<tr>
<td>Real-road driving mode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Careful driving</td>
<td>N.D.</td>
<td>-</td>
</tr>
<tr>
<td>Overtaking driving</td>
<td>20~35 ppm</td>
<td>-</td>
</tr>
<tr>
<td>as traffic required</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

Korea has been working on developing the management standards including test procedures, test mode, and substance limit values, to prevent future cases.

If group members are interested in this issue, we are willing to share our ideas, results, technical data, and expertise with you.

Future Works

Examination of exhaust and harmful substances other than CO

- Identify other substances
- Examine affect on human health
- Update the draft of management standards

Air pollutant (specifically fine dust) concentrations within the vehicle cabin

- Measurement, filtration, purification, and driver notification systems / device
Thank you

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