Key Technical Contents of the China VI Emission Standards for Diesel Fuelled Heavy-Duty Vehicles

New stringent emissions legislation aims to ‘win the blue sky defence war’ in China

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The publication and implementation of the China VI emission standards for diesel fuelled heavy-duty vehicles is one of the important measures to fulfill the ‘blue sky defence’ action plan in China. This paper, by interpreting the background and key technical contents of the China VI emission standards, analyses the basis of the technical requirements and their impact. Moreover, it demonstrates the main differences between the China VI and China V emission standards and the Euro VI regulations, hoping to give the relevant industry in-depth insights into the new standard.

1. Background

By the end of 2017, there were 310 million motor vehicles in China, including 217 million automobiles. Twenty-four cities had more than 2 million automobiles, including seven cities with more than 3 million (Figure 1).

Previous studies have shown that motor vehicles are a prominent source of air pollution in the cities of China. As shown in Figure 2, the nitrogen oxides...
(NOx) emissions from motor vehicles account for 32% of the total NOx emissions in the country (2). As shown in Figure 3, emissions from motor vehicles have become the primary sources of fine particulate matter (PM$_{2.5}$) in Beijing, Shanghai, Hangzhou, Jinan, Guangzhou and Shenzhen (3).

Of all motor vehicles, heavy-duty vehicles are the most significant sources of pollutants. As shown in Figure 4, despite the low proportion of heavy-duty vehicles (currently just 10 million in China), accounting for a modest 4.8% of all motor vehicles, they are responsible for 83.7% and 84% of the NOx and particulate matter (PM) emissions from motor vehicles, respectively (3). The control of emissions from heavy-duty vehicles has long been a top priority to reduce mobile source pollution. Since 2000, China has implemented five stages (China I, II, III, IV, V) of emissions standards for diesel fuelled heavy-duty vehicles. So far, compared with the China I stage emissions standards, control of NOx and PM emissions have been tightened by 78% and 94%, respectively (Figure 5) (4).

To further tighten the control of emissions from diesel fuelled heavy-duty vehicles, the Ministry of Ecology and Environment of the People’s Republic of China issued the China VI emission standards for diesel fuelled heavy-duty vehicles in June 2018, known as the ‘Limits and measurement methods for emissions from diesel fuelled heavy-duty vehicles (GB 17691-2018)’ (5) (hereinafter referred to as ‘China VI’).
The China VI standard proposes stricter emission limits and adds relevant technical requirements while drawing on international experience and taking into account the specific administrative needs of China. Additionally, this standard embodies the many changes in China’s mobile source environmental management system, which will be analysed in detail along with the key technical contents of this standard in the following sections.

2. Key Technical Contents

2.1 Emission Limits (Standard Cycle)

The China VI emission limits with the standard engine cycle are consistent with the Euro VI emission limits and are significantly tightened compared to the China V standard, with the NOx limit tightened by 77% and the PM limit by 67% (Figure 6). ‘Standard cycle’ refers to the specific operating mode of the engine on the engine bench specified in the standard. In the conventional sense, the standard cycle emission limits are the standard emission limits.

The standard also proposes the limits for particle number (PN) emissions. Studies have shown that engines with a diesel particulate filter (DPF) emit far fewer particles than engines without DPF technology (Figure 7) (6). To that end, the emission limits on PN will drive the application of DPF technology that can efficiently and steadily reduce the PM emissions.

The standard also specifies the limit for emissions of ammonia (NH₃). With the tightened limits for emissions of NOx, control of NOx by selective catalytic reduction (SCR) systems becomes a requirement. The limit for emissions of NH₃ requires an ammonia trap to be installed at the end of SCR equipment so as to prevent excessive NH₃ emissions into the atmosphere.

The emission limits set out in this standard are based on the maximum reductions achievable with the most advanced emission control technologies. The implementation of China VI will promote the application of the most advanced emission control technology (SCR and DPF).

2.2 Implementation Date

China VI will be implemented in two stages: VI-a and VI-b according to the strictness of technical requirements. The standard applies to diesel fuelled vehicles and gas fuelled vehicles. As shown in Table I, due to the different levels of readiness of the two industries, the entry into force time of this standard varies for different types of vehicles and different stages.
Urban vehicles are buses, postal vehicles and sanitation vehicles that run mainly in cities. Because the air pollution in urban areas suggests the obvious characteristics of motor vehicle pollution, the implementation of this standard for urban vehicles will be earlier than for other vehicles. The main technical differences between the stages VI-a and VI-b are shown in Table II.

The ‘Three-Year Action Plan to Win the Blue Sky Defence War’ issued by the State Council of the People’s Republic of China (State Council document number 22, 2018) (7) on 3rd July 2018 urges ahead of schedule implementation (by 1st July 2019) of the China VI standard for heavy-duty vehicles in key areas (including the Beijing-Tianjin-Hebei region and surrounding areas, the Yangtze River Delta, the Fenhe and Weihe plains, the Pearl River Delta and the Chengdu-Chongqing region). Higher requirements and tighter schedules pose challenges for the implementation of the standard.

### Table I Implementation Date of China VI Emission Standards

<table>
<thead>
<tr>
<th>Stage</th>
<th>Type of vehicles</th>
<th>Implementation date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage VI-a</td>
<td>Gas powered vehicles</td>
<td>1st July 2019</td>
</tr>
<tr>
<td></td>
<td>Urban vehicles</td>
<td>1st July 2020</td>
</tr>
<tr>
<td></td>
<td>All vehicles</td>
<td>1st July 2021</td>
</tr>
<tr>
<td>Stage VI-b</td>
<td>Gas powered vehicles</td>
<td>1st January 2021</td>
</tr>
<tr>
<td></td>
<td>All vehicles</td>
<td>1st July 2023</td>
</tr>
</tbody>
</table>

### Table II Main Technical Differences Between Stage VI-a and VI-b

<table>
<thead>
<tr>
<th>Technical requirements</th>
<th>Stage VI-a</th>
<th>Stage VI-b</th>
</tr>
</thead>
<tbody>
<tr>
<td>PN requirements under the PEMS test</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Requirements for data transmission of onboard terminal of remote emission management</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Emission requirements at high altitude</td>
<td>1700 m</td>
<td>2400 m</td>
</tr>
<tr>
<td>PEMS test vehicle load range</td>
<td>50–100%</td>
<td>10–100%</td>
</tr>
</tbody>
</table>

### 2.3 Standard Test Cycle for Engine Emissions

Engine bench emissions testing is the basic requirement in the standard, including the transient test and the stationary test. As with the Euro VI regulation, China VI also adopts world harmonised test cycles, including the World Harmonised Transient Cycle (WHTC) and the World Harmonised Stationary Cycle (WHSC), bringing it into line with global technical regulations (GTR).

#### 2.3.1 Transient Cycle

The transient test cycle employed in this standard is based on the WHTC, which includes transient conditions data up to 1800 s (Figure 8). The WHTC adopted in the China VI implements overall lower speed and torque in comparison to the European...
Transient Cycle (ETC) adopted in the standard China V (Figure 9).

The ETC, with its higher loads, was identified as defective during the implementation of the China V standard, particularly for urban vehicles which are characterised by low speed and low load state that leads to lower exhaust temperature, inefficient NOx reduction system (such as SCR) and higher NOx emissions than the emission limits. For the purpose of reducing the high NOx emissions of urban vehicles in the China IV and V standards, the former Ministry of Environmental Protection has added a new standard: the ‘Limits and measurement methods for exhaust pollutants from diesel engines of urban vehicles (WHTC)’ (HJ689-2014) (8), which adopted the WHTC with the lower load and performance characteristics more typical of urban vehicles.

The WHTC adopted in the China VI standard not only has lower load but also introduces a cold start emission test, under which the emissions from engines are weighted from the measurements for cold start (a weight of 14%) and warm start (a weight of 86%). The average lower load and cold start test introduced in the WHTC results in overall lower exhaust temperature of the engine, allowing a more effective evaluation that determines whether the emissions control device works under low speed and low load conditions.

2.3.2 Stationary Cycle

China VI introduces the WHSC, a 13 mode test cycle that is similar to the European Stationary Cycle (ESC) adopted in the standard China V. However,
their conditions and corresponding weights are different. The load of WHSC is lower while the load of ESC is higher (Figure 10). The WHSC is more conducive to testing emissions at low speeds and low loads.

Due to the high exhaust temperature under high speed and high load, the conversion efficiency of the exhaust aftertreatment device is usually high. However, under low speed and low load, the exhaust temperature is generally low, resulting in lower conversion efficiency or even ineffective conversion. In this sense, the WHTC and WHSC test cycles that focus on low speed and low load emissions are more capable of assessing the low temperature performance of an SCR catalyst. This leads to more stringent requirements on the calibration of machinery and the technical upgrading of the aftertreatment industry.

2.4 World-Harmonised Not-To-Exceed Requirements

In addition to the standard cycle test, the China VI and the Euro VI regulations also specify the requirements for the World-Harmonised Not-To-Exceed (WNTE) test, which requires five operating points to be randomly selected from each of the three randomly selected areas in the WNTE control area (Figures 11 and 12) and as for gaseous pollutants, the arithmetic mean of the five operating points in each area should meet the standard requirements. As for PM, the arithmetic mean of the 15 operating points should meet the standard requirements. The limits are shown in Table III.

Before China V, the standard only required to evaluate emissions from engines under the type approval test mode (i.e. standard engine cycle) and did not evaluate emissions under other operating modes. The introduction of the WNTE test requirements can effectively prevent the phenomenon whereby vehicle emission limits are achieved only under the standard test cycle.

2.5 On Road Emission Tests Using Portable Emissions Measurement Systems

The China VI specifies the vehicle portable emissions measurement systems (PEMS) test, which is the emission test requirement for the whole vehicle on real roads. On board PEMS test is an exhaust emission test with a PEMS installed on a vehicle driving on real roads.

Because the road conditions that vehicles travel on vary in a real-world situation, different test routes – including urban, rural and motorway – are classified by vehicle type and allocated according to the percentage of total travel time (Table IV), with a deviation of ±5% allowed.

Under the China VI standard, the emission test for on road vehicles covers gaseous pollutants (NOx, CO) and PN as well as CO2 emissions. The PEMS test in both European and American...
regulations also specifies measurement and limits for total hydrocarbons (THC). However, as the THC emissions from diesel fuelled heavy-duty vehicles are usually very low and the compressed hydrogen required for the flame ionisation detector (FID) as recommended in the regulations is a potential risk, coupled with the high cost of measuring equipment and operational requirements, the PEMS test specified under the China VI does not make a THC test for diesel fuelled vehicles mandatory. To date, no PEMS emission limit has been expressly stipulated in the Euro VI regulation for PM. Given

Fig. 11. WNTE test cycle grids (<3000 rpm)

Fig. 12. WNTE test cycle grids (≥3000 rpm)
the level of air pollution in China, the Chinese government deems it necessary to add relevant requirements for PM in China VI. In view that PEMS-PN test accuracy is better than PEMS-PM test accuracy, China VI makes provisions for the PEMS-PN test and its emission limits.

In terms of the environmental conditions of the PEMS test the China VI standard, based on its own national situation, introduces different requirements for altitude than the EU legislation. Given the fact that a third of the country’s territorial area is above 2000 m, China VI increases the altitude range of the PEMS test to 2400 m (to be implemented from the stage VI-b) to meet the needs of motor vehicle emissions control in high altitude areas and cover provincial capitals such as Kunming city and Xining city.

The data analysis for the PEMS test refers to the work-based window method introduced in the Euro VI regulation, the result of which is the sliding window average of emissions calculated alongside the work done in the engine bench test. While the vehicle can be tested under 10% to 100% load conditions, the selected load should ensure that the average cycle power of the engine is more than 10% of the engine power rating. The final test result requires more than 90% of the valid windows to meet the emission limits. The PEMS emission limits are determined in view of the various operating conditions, environmental conditions, the user’s driving habits and equipment errors in actual vehicle operations. The limits for gaseous pollutants are one and a half times the WHTC limits and the PN limits are twice the WHTC limits.

The PEMS test method under the China VI is a combination of reference to the Euro VI regulation and consideration of China’s actual conditions and experimental studies that have been carried out. China VI is partially modified from Euro VI, so as the vehicles in line with the Euro VI may not satisfy the PEMS test specified in China VI, which is arguably the world’s most stringent emissions requirement. The main differences between the China VI and the Euro VI regulation in the PEMS test are shown in Table V.

The introduction of the PEMS test method for on road vehicles is a major improvement in the measurement methodology of the China VI standard. The compliance of emissions from heavy-duty vehicles has for many years been evaluated by the engine test as opposed to the vehicle test, which has incurred great difficulty in enforcement. The PEMS vehicle road test introduced in the China VI standard clarifies the responsibility of vehicle manufactures, provides methods for vehicle supervision and inspection, and fills the gap of measurement methods for vehicle supervision and enforcement.

### 2.6 Requirements on Combined Tests of Emission and Fuel Consumption

During the implementation of the previous standards, it was found that different versions of

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>CO</th>
<th>THC</th>
<th>NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limits</td>
<td>2000</td>
<td>220</td>
<td>600</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of vehicles</th>
<th>Urban (Speed ≤55 km h⁻¹)</th>
<th>Rural (Speed ≤75 km h⁻¹)</th>
<th>Motorway (Speed &gt;75 km h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1, N1</td>
<td>34%</td>
<td>33%</td>
<td>33%</td>
</tr>
<tr>
<td>M2, M3, N2</td>
<td>45%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Urban vehicles</td>
<td>70%</td>
<td>30%</td>
<td>—</td>
</tr>
<tr>
<td>N3</td>
<td>20%</td>
<td>25%</td>
<td>55%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Euro VI</th>
<th>China VI-a</th>
<th>China VI-b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Conditions</td>
<td>Max altitude: 1700 m Min atmospheric pressure: 82.5 kPa</td>
<td>Max altitude: 1700 m Min atmospheric pressure: 82.5 kPa</td>
<td>Max altitude: 2400 m Min atmospheric pressure: 73 kPa</td>
</tr>
<tr>
<td>Pollutant</td>
<td>NOx, CO, THC (diesel fuelled vehicles), NMHC and CH₄ (gas fuelled vehicles) and CO₂</td>
<td>NOx, CO, THC (optional for diesel fuelled vehicles), PM (optional) and CO₂, and NOx concentration limits</td>
<td>NOx, CO, THC (optional for diesel fuelled vehicles), PM (optional), CO₂ and PN (optional for gas fuelled vehicles), and NOx concentration limits</td>
</tr>
<tr>
<td>Vehicle load</td>
<td>50–100%</td>
<td>50–100%</td>
<td>10–100%</td>
</tr>
</tbody>
</table>
the vehicle electronic control unit (ECU) had been applied to pass the different tests, such as using the ‘emission version’ to pass the emission test, and the ‘fuel consumption version’ to pass the fuel consumption test. Vehicles that are calibrated with fuel consumption standards usually have higher emissions despite the lower fuel consumption, and thus cannot meet emission standards. As shown in Figure 13, the emission and fuel consumption test data obtained by the China VI standard drafting group under the two ECU calibration versions with tests carried out on the vehicle chassis dynamometer. The test results fully illustrate the difference between the two versions of the ECU calibration (fuel consumption version and emission version). The emissions from vehicles with the fuel consumption calibration version are more than twice those of the vehicles with emission calibration version.

In view of this problem, the China VI standard specifies the relevant requirements for a ‘combined test for emission and fuel consumption’. The vehicles should also be measured for emissions as stipulated in this standard when tested for fuel consumption. The gaseous pollutants and PM emissions must satisfy the PEMS emission limits set out in this standard and the test results must be disclosed. The introduction of this requirement will encourage the simultaneous satisfaction of emission and fuel consumption standards.

2.7 Other Main Technical Requirements

In addition to the technical requirements mentioned above, the China VI standard, by referring to the Euro VI regulation, also tightens the durability requirements, on-board diagnostic (OBD) requirements and NOx control requirements. Meanwhile, compared with the Euro VI regulation, the China VI standard introduces relevant administrative regulations conforming to the new circumstances and ideas of China’s motor vehicle emission regulation, including:

- technical requirements for a remote emission control vehicle terminal, providing technical support for the implementation of remote emission control by competent authorities in the future
- a method of OBD function check on the vehicle to ensure that competent authorities can effectively supervise the function of the vehicle OBD
- the requirement for permanent fault code storage to prevent manual elimination of fault information stored in the OBD system and ensure that faulty vehicles can be effectively identified by competent authorities during supervision
- the requirement for the warranty period of the emission control device to safeguard legitimate user interests
- the requirement for vanadium-based SCR, requiring OBD to monitor the temperature of vanadium-based SCR to prevent emissions of vanadium containing compounds
- the position and orientation requirements of the exhaust exit to facilitate the vehicle emission test, the observation of a remote sensing device and the implementation of a PEMS test.

3. Conclusion

The formulation and implementation of the China VI emission standard for diesel fuelled heavy-duty vehicles is one of the important measures for carrying through the 13th Five-Year Plan of China (9) and is also of great significance for preventing heavy-duty vehicle emission pollution, pushing forward the upgrading of China’s automobile industry and promoting domestic vehicles to be geared to international standards. Characterised by high technology and a long production chain, the automobile industry generates retail sales of automotive consumer goods amounting to more than 4 trillion Yuan or approximately 11% of the total retail sales of social consumer goods. In that regard, the implementation of this standard is sure to have a significant impact.

Based on the world’s most advanced emissions standards while adding relevant requirements for China, the China VI is the most stringent vehicle legislation worldwide, which is in line with the need...
for tough pollution control for heavy-duty vehicles in China and demands ever higher requirements for the automotive industry.

As proposed in the ‘Three-Year Action Plan to Win the Blue Sky Defence War’, the ahead-of-schedule implementation of this standard in key areas, the Pearl River Delta region and the Chengdu-Chongqing region is less than a year away at the time of writing, which not only urges manufacturers to speed up the R&D and production schedules in order to comply with the standard in accordance with the prescribed time limits but also places higher requirements on the competent authorities that are expected to further strengthen supervision, improve the joint law enforcement system and build an integrated supervision and control system within China. Only with industry wide effort and the joint commitment of society can we ensure the successful implementation of China VI, effectively control emissions and contribute to the actions for ‘winning the blue sky defence war’.

Acknowledgments

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