

Light-Duty Vehicle Emissions Control: A Brief Introduction to the China 6 Emissions Standard

The key regulation improvements and areas for further developments are reviewed

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China has been the world's largest new vehicle market since 2009 and new vehicle sales exceeded 28 million in 2016, among which more than 87% were light-duty vehicles (LDV). In order to reduce emissions and control air pollution China has recently adopted the China 6 emissions standard for LDV which is 50% more stringent than China 5. Besides strengthening the tailpipe emissions limits, China 6 changes the emissions test driving cycle to the Worldwide Harmonised Light-Duty Vehicle Test Cycle (WLTC), adds real road emissions requirements and significantly strengthens evaporative emissions control. This paper introduces the standard development background, summarises the key technical improvements and discusses the areas for further improvements in future.

Introduction

China has been the world's largest vehicle market since 2009 and in 2016 annual new vehicle sales exceeded 28 million, representing 13.7% growth compared to 2015 despite the poor economy, as shown in **Figure 1** (1, 2). As a result, the vehicle population on the road reached 194 million (not including about 100 million motorcycles) by the end of 2016 (3, 4), among which more than 87% were LDV. Vehicular emissions have become the leading contributor to air pollution in Tier I cities such as Beijing, Shanghai, Guangzhou, Shenzhen and Hangzhou, and are increasingly contributing to pollution in other cities due to industry relocation and coal consumption control (5, 6). In order to control vehicle emissions and reduce the impacts on air quality and public health, the Ministry of Environmental Protection (MEP) designated the task of developing the China 6 emissions standards for both LDV and heavy-duty vehicles (HDV) to China Research Academy of Environmental Sciences (CRAES) in 2015. This paper introduces the emissions standard for LDV and summarises the key technical contents.

In order to complete the task in a short period CRAES formed a core working team including Beijing Institute of Technology, China Automotive Technology and Research Center, Xiamen Environment Protection Vehicle Emission Control Technology Center and Beijing Vehicle Emissions Management Center, and established five technical task groups with more than 40 automotive manufacturers participating. The five technical tasks included test technologies

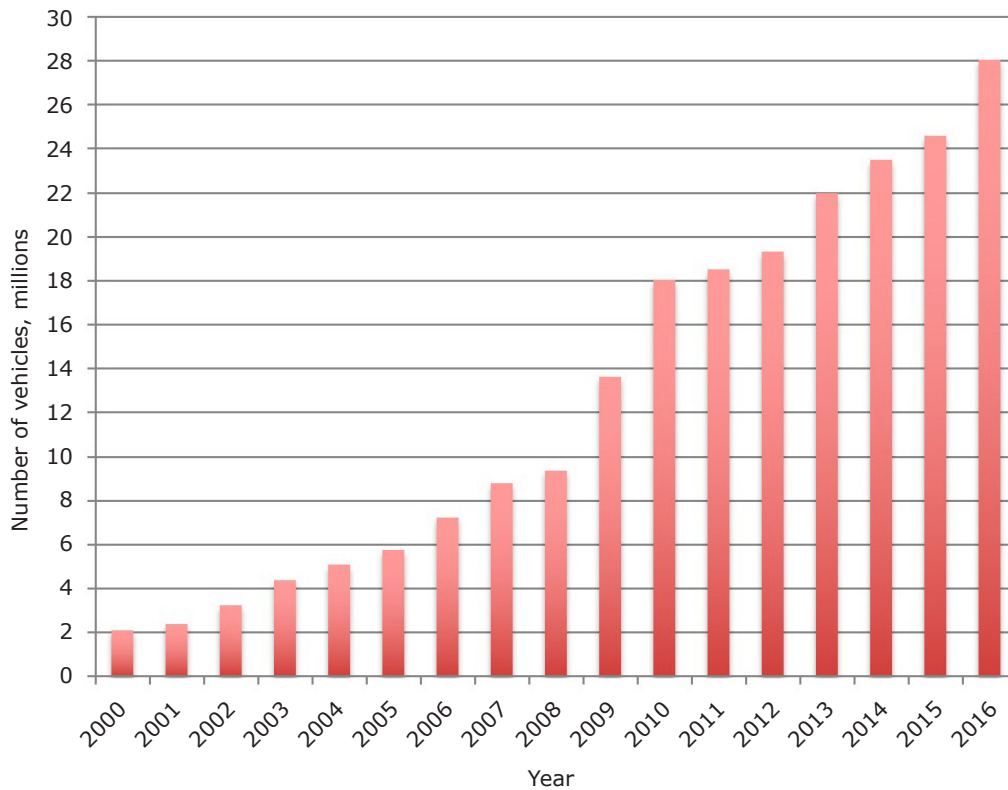


Fig. 1. Annual new vehicle sales in China since 2000

and facilities, reference fuels, fuel evaporation, test cycles, procedure and limits, and the on-board diagnostics (OBD) system. The standard development process could be divided into four phases: the first phase was aimed at aligning opinions on the necessity of developing China 6 and conducting preliminary analysis on some technical issues such as particulate number (PN) and OBD before 2015; the second phase finished the working group formation, working plan development, task allocation, international emissions regulations collection and translation, capacity building and information and experience exchange with field stakeholders by training, workshops and study tours from January 2015 to June 2015; the third phase had more than 40 workshops and meetings, established solutions for most technical problems, and developed the draft standard from July 2015 to April 2016; and the fourth phase completed the standard public commenting, technical review and administration approval from May 2016 to December 2016. On 23rd December 2016 the MEP and General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) jointly published the final

China 6 emissions standard for LDV, i.e. limits and measurement methods for emissions from LDV (China 6). The standard will be implemented in two phases: by 1st July 2020 all new LDVs sold and registered in China must meet China 6a and by 1st July 2023 all new LDVs sold and registered in China must meet China 6b.

Key Regulation Improvements

1. Emissions Test Driving Cycle

China adopted the New European Driving Cycle (NEDC) as the test cycle from China 1 to China 5 since 2000. NEDC is simple and easy to duplicate, but does not well represent real road driving conditions in China. Therefore, China considered changing the test cycle either by developing its own driving cycle or by choosing an alternative. The working group compared the differences between the NEDC, the US Environmental Protection Agency (EPA) Federal Test Procedure (FTP-75) and the WLTC, and found that the WLTC widely represents various driving conditions and covers a much broader engine speed and loading range (**Figures 2 and 3**).

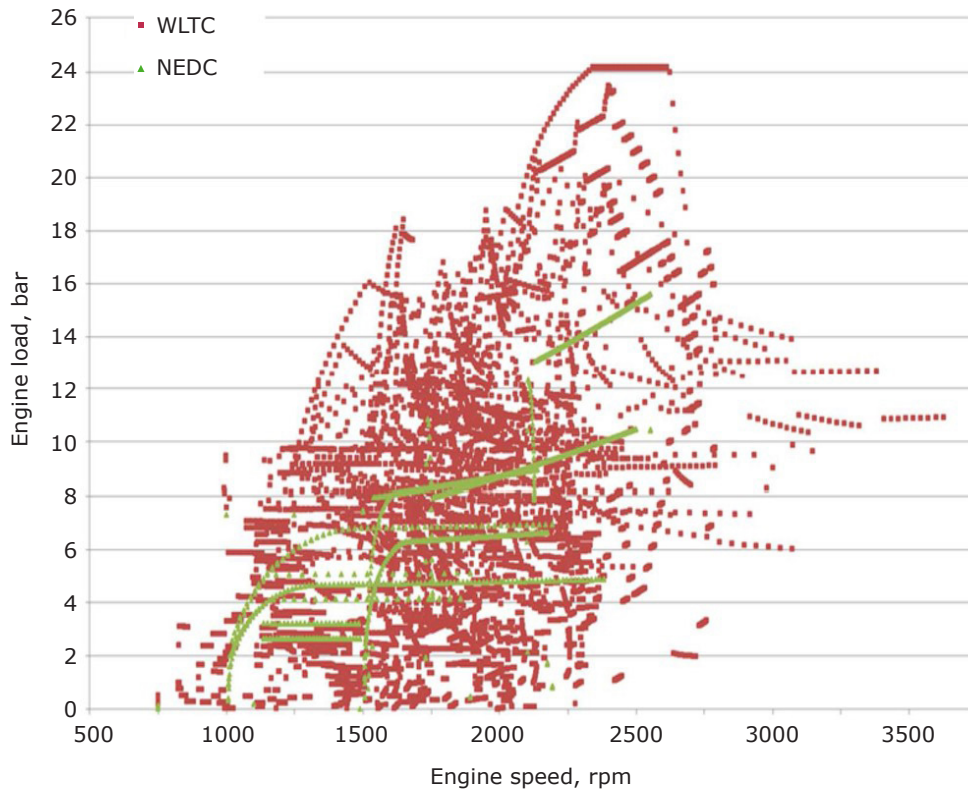


Fig. 2. Comparison between NEDC and WLTC

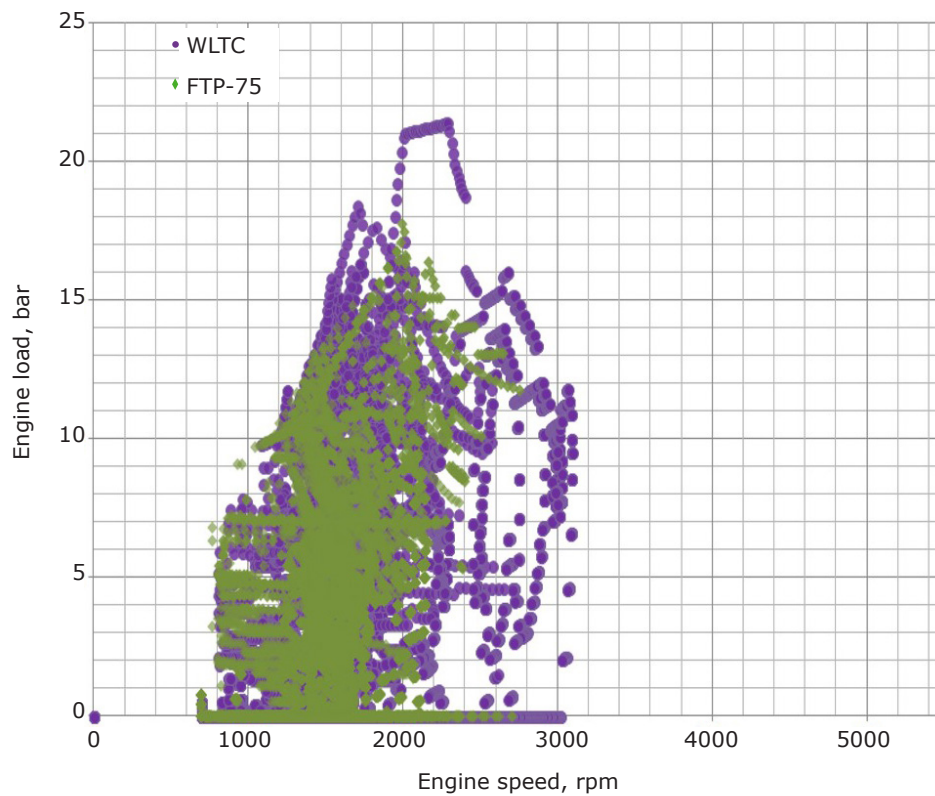


Fig. 3. Comparison between FTP-75 and WLTC

In order to test how well the WLTC represents driving conditions in China, the working group collected driving cycles in 20 representative cities with different city scales, altitudes, locations and terrain. Five cars were used to chase the traffic in each city during working days covering both peak hours and off-peak hours and weekends in different areas including urban, urban-rural and rural areas on different roads for five days. Based on the collected data, the working group built a China Light-Duty Vehicle Driving Cycle (CLDC) and compared the characteristics with the WLTC (Figure 4 and Table I).

Across the ten characteristics at four speed ranges the results showed the frequency with less than $\pm 10\%$ variance between WLTC and CLDC was 58% and the frequency with less than $\pm 20\%$ variance was 80%. But some characteristics, such as idle ratio at ultra-high speed, had as high as 83% variance, which will require attention in future.

The working group further tested the emissions of seven cars meeting China 4 and above with five different driving cycles including NEDC, WLTC, FTP-75, Vehicle Emission Control Center (VECC) (1) and CLDC. The results showed that the emissions during the WLTC were in the middle compared to the emissions with all other driving cycles. Compared to the FTP-75, the WLTC produced a higher concentration of gaseous pollutants despite lower particulate concentration, indicating that the WLTC is more stringent than the FTP-75 to control gaseous pollutants (Figure 5). The fuel consumption of two cars were also tested with the WLTC and the NEDC and compared to real road fuel

consumption. In summary, WLTC resulted in higher fuel consumption than NEDC and there was also a smaller difference in the fuel consumption between WLTC and the real road at about 14.0% compared to about 22.5% between NEDC and real road fuel consumption (Figure 6).

In addition to the analysis above, it was taken into account that China had participated in the discussion and development of the WLTC and procedure and committed to deploy the standards. Therefore the working group confirmed that WLTC would be used to replace NEDC in China 6.

2. Tailpipe Emissions Limits and Implementation

China is facing growing challenges to clean up its air. If China continued following the European regulation, which will phase in the WLTC from 2017 but keep the Euro 6c limits without further strengthening, it would be difficult for China to reduce emissions from its fast growing LDV fleet. Considering the Tier 3 emissions standards in the USA as a benchmark as well as available technologies on the market, the working group therefore suggested 40–50% more stringent limits (Figure 7). Diesel vehicles and gasoline vehicles were combined to comply with the same emissions limits. In addition, the standard adds particle number limits for gasoline vehicles for the first time. In order to provide enough leading time China 6 is going to be implemented in two phases: China 6a by 1st July 2020 and China 6b by 1st July 2023.

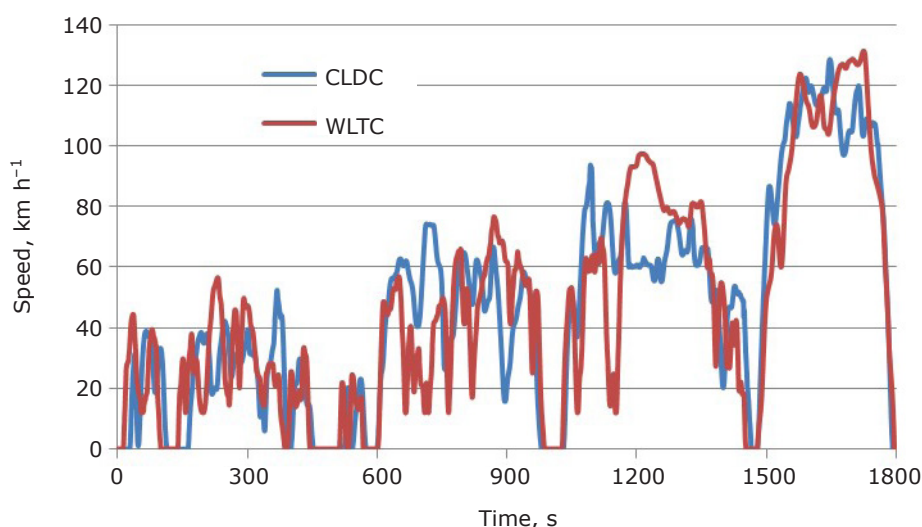


Fig. 4. Comparison between WLTC and CLDC

Table I Characteristics of the World Harmonised Light-Duty Vehicle Test Cycle (WLTC) and China Light-Duty Vehicle Driving Cycle (CLDC)

Speed range	Cycle	Driving distance, km	Average speed, km h ⁻¹	Maximum speed, km h ⁻¹	Maximum acceleration, m s ⁻²	Maximum deceleration, m s ⁻²	Relative positive acceleration	Acceleration, %	Deceleration, %	Idle, %	Steady, %
Low	WLTC	3.09	18.9	56.5	1.47	-1.47	0.205	28.4	31.1	24.5	15.8
	CLDC	2.85	17.4	52.4	1.24	-1.93	0.205	28.4	23.8	29.2	18.7
Middle	WLTC	4.76	39.5	76.6	1.58	-1.50	0.196	36.0	30.3	10.6	23.1
	CLDC	5.15	42.8	74.3	1.03	-1.67	0.190	31.4	30.9	12.0	25.6
High	WLTC	7.16	56.7	97.5	1.58	-1.50	0.132	29.0	27.7	6.4	36.9
	CLDC	7.08	56.1	93.7	1.31	-1.89	0.169	31.2	25.9	4.4	38.5
Ultra-high	WLTC	8.25	92.0	131.3	1.03	-1.22	0.125	37.2	32.2	1.5	29.1
	CLDC	8.45	94.1	128.5	1.21	-1.29	0.174	35.3	31.6	2.8	30.3
Overall	WLTC	23.27	46.5	131.3	1.58	-1.50	0.152	31.9	30.2	12.6	25.3
	CLDC	23.54	47.1	128.5	1.31	-1.93	0.179	31.1	27.4	14.1	27.4

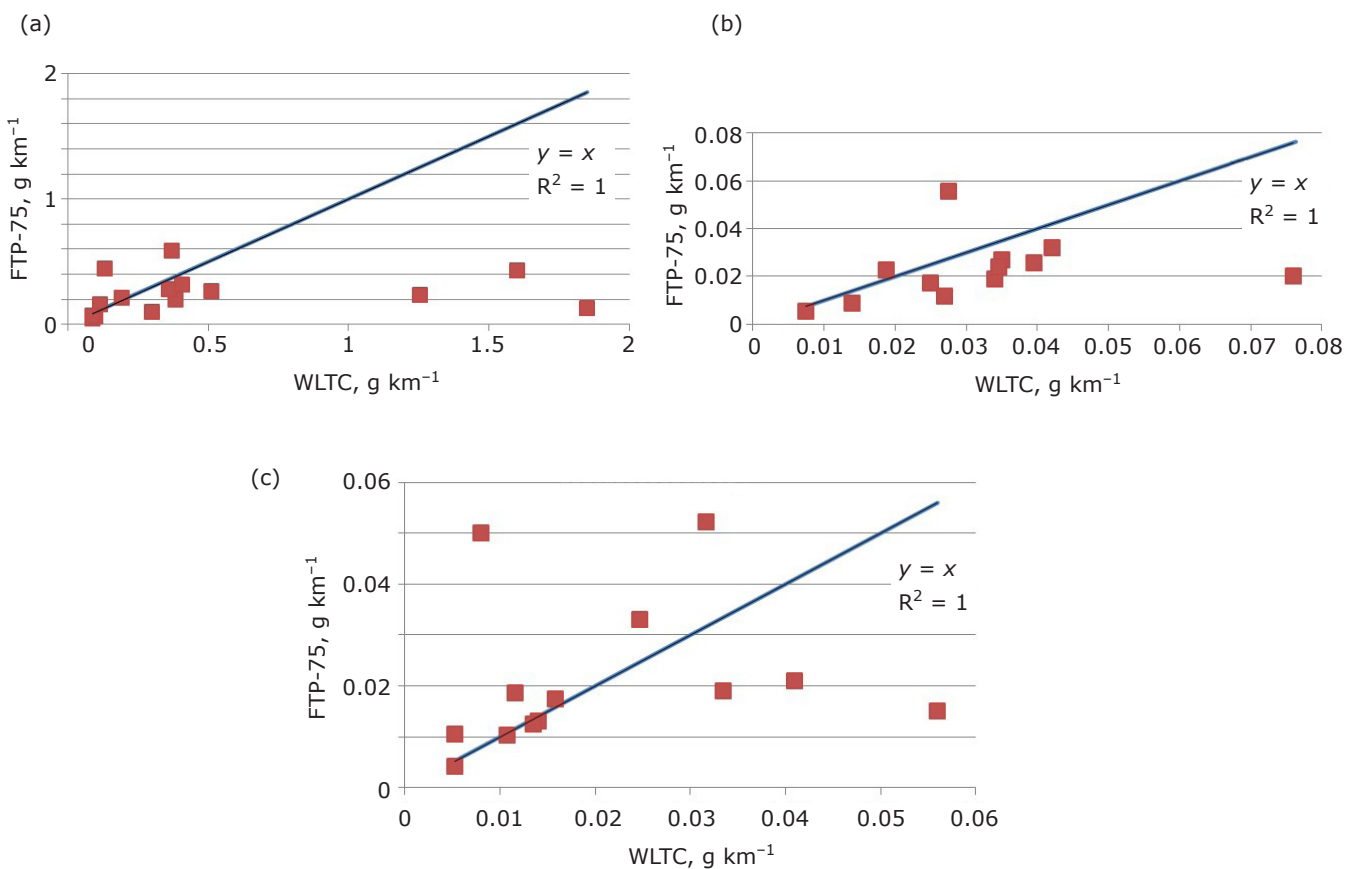


Fig. 5. Emissions comparison between FTP-75 and WLTC: (a) CO; (b) hydrocarbons; and (c) NOx

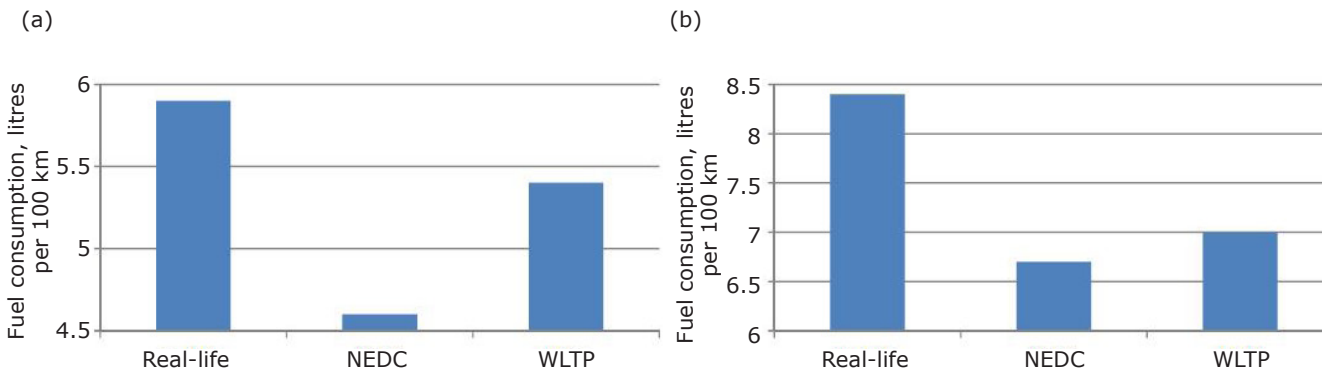


Fig. 6. Fuel consumption comparison between WLTC, NEDC and real road driving: (a) petrol car, 1.2 l, manual; (b) petrol car, 1.6 l, manual

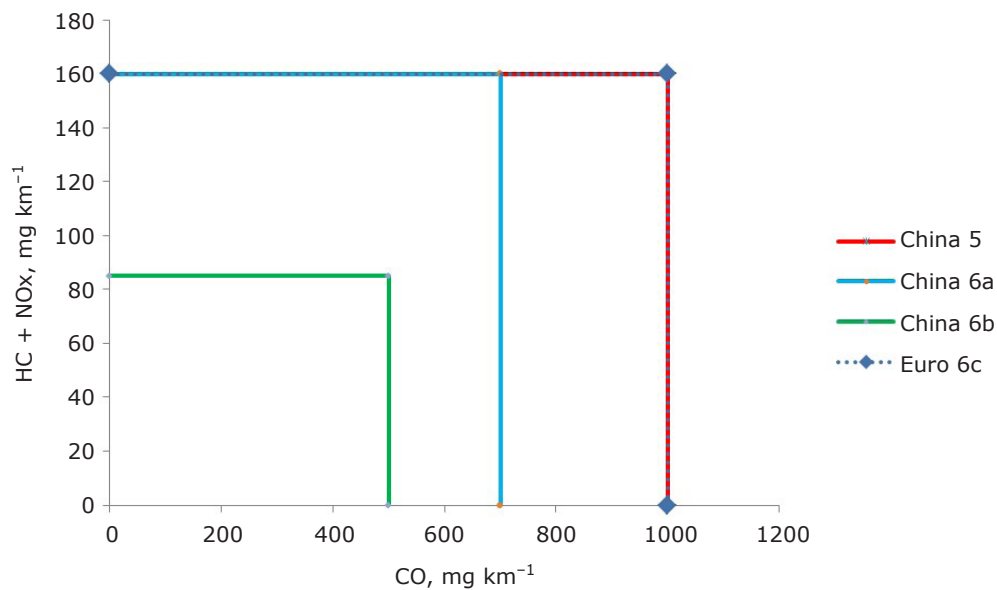


Fig. 7. Limits comparison of China 5, China 6a, China 6b and Euro 6c

The feasibility of meeting the standard was evaluated by analysing China 5 vehicle type approval data and conducting emissions tests on 44 cars following the World Harmonised Light-Duty Vehicle Test Procedure (WLTP) and the WLTC.

Analysis of type approval emissions data of 8600 LDV (complying with China 5) after 160,000 km deterioration showed 74% and 33% of these vehicles could meet China 6a and 6b respectively. **Table II** summarises the China 6 compliance rates of 44 gasoline cars (complying with China 5, Euro 6c and US Tier 2/3) based on the emissions tests; 18% and 16% of these 44 cars could meet China 6a and 6b respectively. The results proved China 6 is stringent but also achievable.

Automotive manufacturers sent these 44 cars with the goal to test whether their cars could meet

the potential China 6b limits directly. Therefore, it is clear that there is no significant difference between the compliance rates of China 6a (18%) and 6b (16%). In addition, although the compliance rates for each category of air pollutants might be high, considering all six pollutants, only 16% cars could meet China 6b. Not all the cars had a gasoline particulate filter (GPF) and only 30% of the cars met the PN limits, which suggests that GPF will be essential in future for gasoline vehicles to meet the standard.

The standard also includes the control of greenhouse gas emissions such as nitrous oxide (N₂O) and carbon dioxide (CO₂). Automakers only need to report the CO₂ value for the vehicle type and do not need to meet any emissions limits because there is already a mandatory fuel efficiency requirement

Table II China 6 Compliance Rates of Selected Gasoline Cars

	HC ^a	CO	NOx	NMHC ^b	PM ^c	PN ^d	Overall
6a	95%	80%	96%	96%	81%	30%	18%
6b	95%	72%	81%	93%	70%	30%	16%

^aHC = hydrocarbon

^bNMHC = non-methane hydrocarbons

^cPM = particulate matter

^dPN = particulate number

regulated by the Ministry of Industry and Information Technology (MIIT). The main purpose is to avoid any policy leakage, such as optimising vehicles to meet different regulations with separate tests, due to separate administration of tailpipe air pollutants emissions by MEP and fuel efficiency by MIIT.

3. Real-Road Emissions

It is real emissions on the road that matter to air quality. In order to reduce the potential risks of high emissions on the road despite good emissions test results in the laboratory, the working group referred to the European regulations and included real driving emissions (RDE) requirements in the standard. However, it expands the altitude boundary from 1300 m in the European regulation to 2400 m considering many land areas in China have much higher altitudes. Evaluation was conducted with several gasoline and diesel vehicles by comparing

their RDE results to the laboratory test emissions with different driving cycles. Results showed the RDE of nitrogen oxides (NOx) were significantly higher than most laboratory test results and could be as high as 8.6 times (**Figure 8**).

Because RDE is a new emerging regulation requirement and may still need further evaluation and demonstration, automotive manufacturers only need to monitor and report the RDE results of NOx, PN and carbon monoxide before 1st July 2023 and the proposed conformity factor for both NOx and PN, the value of which is 2.1, needs further confirmation before 1st July 2022.

4. Evaporative Emissions Control

With more stringent tailpipe emissions control of the evaporative emissions of reactive organic gases from refueling, running loss, permeation, hot soak

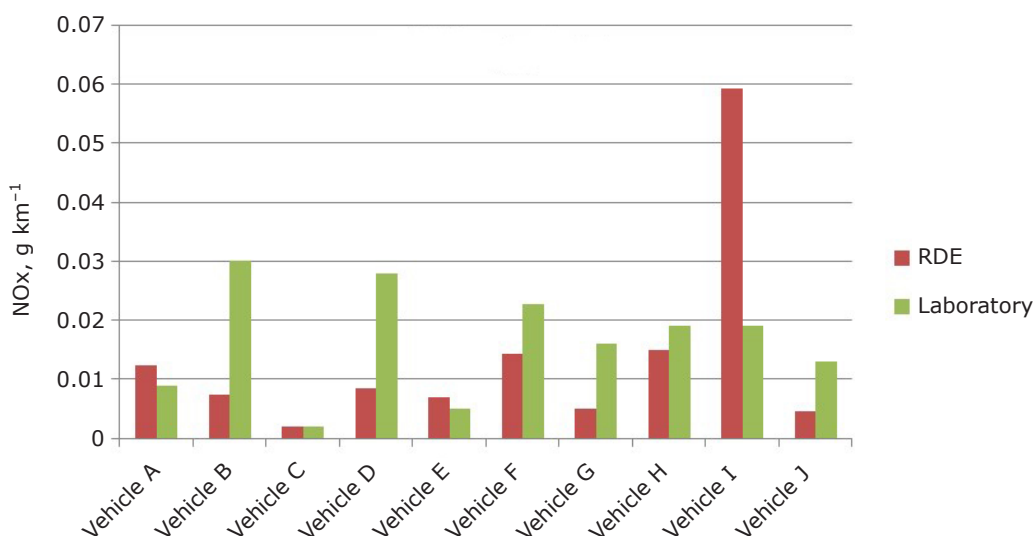


Fig. 8. NOx emissions comparison between RDE and lab tests

and diurnal are getting much more important. China has followed the European regulations and requires all LDVs to control evaporative emissions. However, the regulation is not stringent and does not include refueling evaporative emissions. As a result, the evaporative emissions in China could be as high as 8800 g per year per vehicle compared to 500 g per year per vehicle in the USA. The new standard significantly strengthens the evaporative emissions limits and adds refueling emissions control. Compared to the previous standard, the new standard reduces vehicle evaporative emissions limits from 2.0 g per test previously

to 0.7 g per test, increases the test temperature from within the range 20°C–30°C to 38±2°C and simplifies the diurnal emissions test from 72 h in the USA standard to 48 h. In addition, borrowing experience from the USA the new standard adds control of refueling evaporative emissions and sets the limits at 0.05 g l⁻¹, equal to the US Tier 2 level.

The working group tested the vehicle evaporative emissions of ten gasoline LDVs which meet the China 5 standard with the new test procedures and found not all the vehicles could meet the new emissions limits, with the highest emissions at about 5.8 g per test (Figure 9). Two of the ten

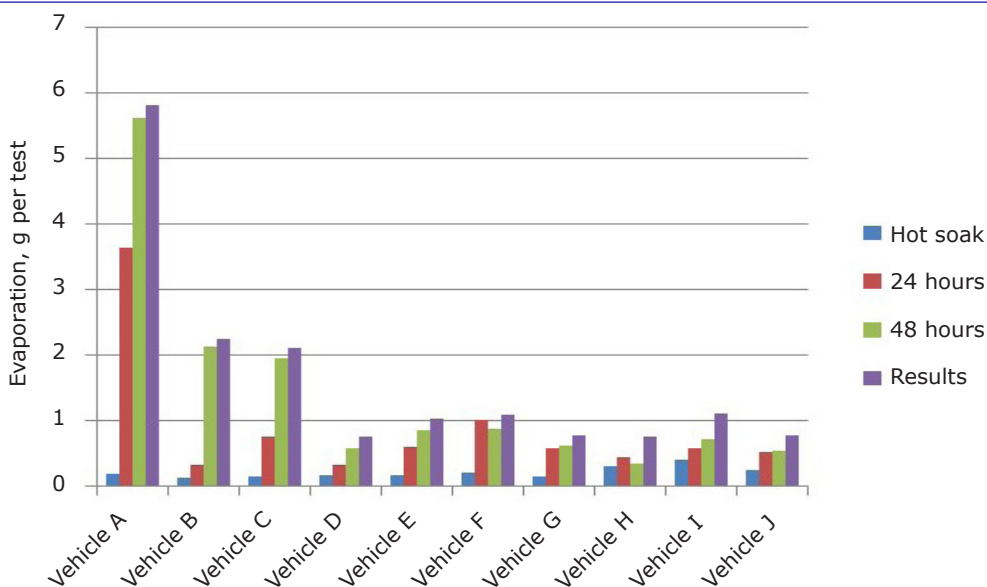


Fig. 9. Evaporative emissions of ten gasoline cars

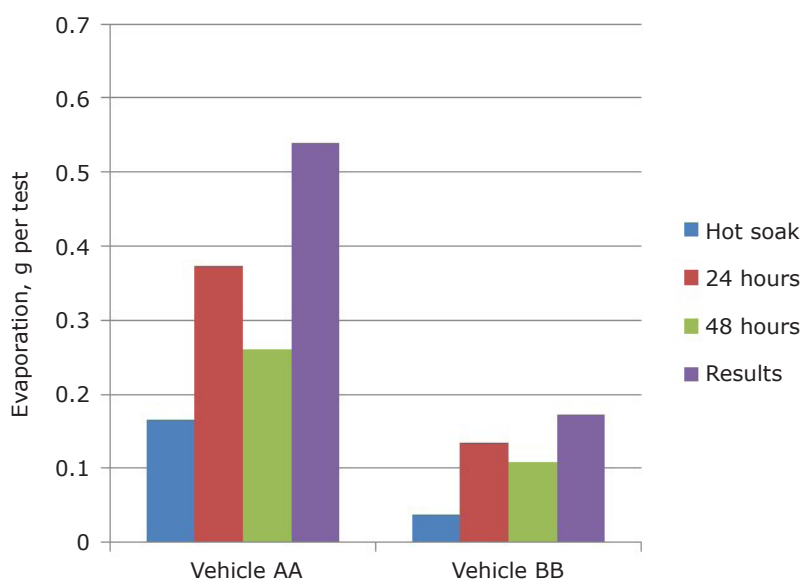


Fig. 10. Evaporative emissions after retrofitting improvements

vehicles were tested again after being retrofitted by increasing the size of the carbon canister and improving heat insulation. The results showed the evaporative emissions were reduced significantly, even lower than 0.35 g per test as required in US Tier 3 (Figure 10). These results proved the limits are achievable in China and could be further strengthened in future.

5. Other Key Improvements

Besides the major improvements mentioned above, the China 6 standard has additional changes as below: (a) increasing the emissions durability mileage from 160,000 km in China 5 to 200,000 km in China 6b while keeping the mileage the same as in China 6a and allowing standard catalyst bench ageing for durability testing; (b) strengthening cold start emissions at low temperature by requiring NO_x emissions control at 0.25g km⁻¹ and 33% more stringent limits for other air pollutants; (c) improving the OBD system by preventing trouble codes from being deleted without fixing the problem, including in-use performance ratio (IUPR) for OBD, adding monitoring items with specific conditions and requiring key components of hybrid vehicles, air conditioning systems and cold start emissions control to be monitored; (d) including hybrid vehicle emissions testing and limits; and (e) simplifying the process of deciding new vehicle product conformity and in-use vehicle compliance.

Discussion

In order to control the oil consumption and greenhouse gas emissions from the transportation sector, China's MIIT is adopting mandatory light-duty passenger fuel economy standards and aims to achieve an average of 5 l per 100 km by 2020. The current fuel efficiency test methodology is based on the NEDC, which is different from the WLTC used in the China 6 emissions standard. At the same time, MIIT has designated the China Automotive Technology and Research Center (CATARC) to develop a new driving cycle, known as the China Automotive Testing Cycle (CATC), which could better represent the driving conditions in China so that the fuel consumption consumer experience on the road could be similar to the test results in the laboratory. Whether the test cycle used is NEDC or CATC, if a different driving test cycle is used for the air pollutant emissions test

and the fuel efficiency test, there could be a risk of policy leakage and automotive manufacturers could optimise their vehicles to meet the two regulations separately, while on-the-road air pollutants emissions and fuel efficiency might not be able to meet both regulations.

Another group in CATARC is now developing the Phase V fuel economy standard for light-duty passenger vehicles, which will phase in from 2021 and aim to achieve an average of 4 l per 100 km by 2025. MIIT plans to complete CATC in 2017 and deploy it in this new fuel economy standard. Having a consistent test cycle and procedure will not only help achieve both goals of reducing air pollutant emissions and fuel consumption at the same time, but will also help automotive manufacturers reduce the cost of complying with two regulations.

Considering the technical capacity of domestic automotive manufacturers and vehicle emissions test organisations and significant changes to previous standards, with some new requirements introduced for the first time, the standard still has the potential to be more stringent than the US Tier 3 in some aspects, such as OBD requirements, evaporative emissions and durability mileage. The RDE also need close monitoring and evaluation to ensure the effectiveness of the regulation.

Acknowledgement

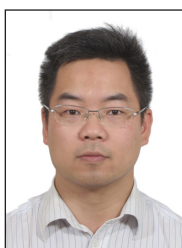
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