Research on the Situation of In-use Consistency of China V Heavy Diesel Vehicles in Shenzhen

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Abstract. In order to explore the current status of in-use compliance of China V heavy-duty diesel vehicles in Shenzhen, five China V heavy-duty diesel vehicles were tested for NOX emissions using the LugDown cycle, and CO, NOX, and PM emissions were tested for these vehicles using the Portable Emissions Measurement System (PEMS). The test results showed that all 5 vehicles meet the NOX limit requirements of the LugDown test method, and 2 vehicles exceeded the limit requirements of the PEMS test method. For 3 vehicles below the PEMS test NOX limit, the difference in the average value of the two test methods was 14%-18%, and the median difference was 1%-63%; For the two vehicles that exceeded the PEMS test NOX limit, the average difference was 32%-63%, and the median difference was 81%-127%. For vehicles with higher NOX emissions, the LugDown test was not able to reflect the actual situation of real driving emission well. The particulate emission test results showed that the difference in the removal efficiency of different diesel particulate filter could reach more than 113 times, and the difference in the technology of cleaning in engine could reach more than 6 times. The study showed that the current status of compliance of in-use China V standard heavy-duty diesel vehicles was not optimistic.

Keywords: Shenzhen; China V heavy-duty diesel vehicles; LugDown cycle; Portable Emissions Measurement System (PEMS); current situation of in-use compliance

1. Introduction

With the increasing contribution of traffic emission particulate matter (PM) pollution, exhaust emissions directly threaten people's health [1], and diesel vehicles are the focus to control the PM emission. National and local governments have introduced various control measures [2], among which improving emission standards is an important measure to start from the source. Since July 1, 2017, heavy duty diesel vehicles have implemented the China V emission standards in Shenzhen and some models must be equipped with diesel particulate filter (DPF). China V heavy-duty diesel vehicles are accounting for the largest proportion of diesel vehicles in Shenzhen, and its in-use consistency status is of great significance to the control of heavy-duty diesel vehicle emission in Shenzhen.

The vehicle models based on type approval can not reflect the road emissions of vehicles very well [3-5], and some domestic studies have also drawn the same conclusion [6-7]. On September 19, 2017, the Ministry of Ecology and Environment issued HJ 857-2017 [8], stipulating the measurement methods and limit values of portable emissions measurement system (PEMS) as the standard for in-use consistency inspection of heavy-duty diesel vehicles. The road emission test requirements and limits of the vehicle were added in the subsequent China VI emission standard [9]. PEMS test is not...
suitable for large-scale measurement due to high cost and complicated process. On September 27, 2018, the Ministry of Ecology and Environment issued "limits and measurement methods of pollutants emission from diesel vehicles (free acceleration method and loading deceleration method)" (GB 3847-2018) [10], which improved the measurement standards of in-use vehicle pollution emission. The LugDown testing method uses the loading device to simulate the road driving cycles of the vehicle, which can better reflect the actual emission of the vehicle [11]. However, according to the research of Wang Junjun [12], Shuang Ju Rong [13], etc., the LugDown measurement method in GB 3847-2005 [14] has some problems, such as testing results are unstable and equipment performance needs to be improved. The validity of LugDown measurement method in GB 3847-2018 needs to be studied.

Based on LugDown and PEMS, this paper studies the in-use consistency status of China-V heavy-duty diesel vehicles in Shenzhen. Through the comparative analysis of the data of the two testing methods, the simulation and measurement level of LugDown on road emission is studied.

2. Design of Experiment

2.1 Experimental Vehicle

According to several heavy diesel vehicle models with a large proportion in Shenzhen (diesel vehicle models whose categories are M and N and whose maximum gross mass is greater than 3500 kg). 5 vehicles are selected for PEMS test and LugDown test respectively, and the main technical parameters of these vehicles are shown in table 1. Vehicle A, B, C and D adopt a selective catalytic reduction (SCR) method to treat NO\textsubscript{x}, the vehicle E uses an exhaust gas recirculation system (EGR) to treat NO\textsubscript{x}; vehicle A, B and E are equipped with DPF to filter exhaust particulate matters, while vehicle C and D are not equipped with after-treatment devices for exhaust particulate matters.

| Item                  | Vehicle A | Vehicle B | Vehicle C | Vehicle D | Vehicle E |
|-----------------------|-----------|-----------|-----------|-----------|-----------|
| Fuel Type             | Diesel    | Diesel    | Diesel    | Diesel    | Diesel    |
| Maximum Total Mass(kg)| 3790      | 4495      | 4495      | 4495      | 4495      |
| Rated Power(kW)       | 85        | 85        | 115       | 110       | 95        |
| Maximum Net Power / Rotating Speed(kW/rpm) | 83/3200  | 83/3200  | 110/3200  | 103/3200  | 86/3200  |
| Date of Initial Registration Mileage(km) | 2019-5   | 2020-6   | 2017-11   | 2017-11   | 2020-4   |
| Emission Standard     | China V   | China V   | China V   | China V   | China V   |
| Engine                | Domestic  | Domestic  | Domestic  | Import    | Domestic  |
| After-Treatment Device| DOC+DPF+SCR | DOC+DPF+SCR | DOC+SCR | DOC+SCR | EGR+DOC+DPF |

2.2. Experimental System

PEMS equipments mainly include SEMTECH ECOSTAR vehicle emission test system produced by American Sensor Company, which mainly includes several emission test modules, an exhaust flow test module, a GPS module, an environmental temperature and humidity test module, and so on. The emission test modules used in this experiment include a fuel economy analyzer (SEMTECH-FEM), a Nitrogen oxides analyzer (SEMTECH-NO\textsubscript{x}), a Particulate matter real-time measurement system
(SEMTECH-CPM) and an Equivalent proportion sampling dilution system (SEMTECH-MPS). SEMTECH-FEM uses the non-dispersive infrared (NDIR) technology to measure CO and CO₂, and the electrochemical or paramagnetic technology to measure O₂. SEMTECH-NOₓ uses the non-dispersive ultraviolet (NDUV) technology to directly measure NO and NO₂ at the same time to obtain NOₓ values. SEMTECH-CPM uses ion migration technology and Faraday cup electrometer measurement method to measure the particulate matter mass concentration in real-time. SEMTECH-MPS uses Venturi effect design to line with US EPA CFR40 part1065 and ISO16183 requirements, and remote dilution design to dilute the exhaust gas sample into a stable state near the tailpipe in order to reduce the loss of particulate matters during transportation.

The LugDown test equipments include a chassis dynamometer (ACCG-3) manufactured by Shenzhen Anche Inspection Co Ltd, a Gas analyzer (MQW-5102) manufactured by Zhejiang University Mingquan Science and Technology Co Ltd and a thermohygrograph (DPH-103) manufactured by Nanjing Hanbang Information Technology Co Ltd.

2.3. Experimental Methods

The PEMS test method is in accordance with the on-board measurement method for road emission of heavy-duty vehicles specified in HJ857-2017, including vehicle preparation, route selection, equipment installation and preheating, starting and ending zero marking, calibration and so on. LugDown is carried out according to the test method specified in GB3847-2018, including vehicle preparation, test procedure, exhaust test, unloading procedure, etc.

3. Results and Analysis

3.1. Analysis of In-Use Consistency Status

1) In-use consistency analysis based on PEMS testing. The emission concentration values of 5 vehicles based on the power are calculated and compared with the China V heavy-duty diesel vehicle emission limit specified in HJ857-2017, as shown in figure 1. Firstly, the CO emission concentration values of five vehicles are compared and analyzed, and the CO emission concentration is far below the emission limit of 6.00 g/kWh. The emission concentrations of vehicles C and D are relatively high. The key factor is that the two vehicles have been used for a long time, the mileage is relatively long, the DOC has thermal aging phenomenon after working at high temperature for a long time, and the CO light-off temperature increases, resulting in the reduction of CO conversion efficiency [15-16]. Therefore, the administrative requirements for vehicle owners to carry out regular after-treatment device maintenance plays an important role in reducing vehicle emissions. In general, the CO emission limit of in-use diesel vehicles is far below the standard emission limit, and the in-use consistency is in good condition.

![Figure 1. Comparison of CO emission concentration of test vehicles.](image-url)
The comparative analysis of NO\textsubscript{X} emission concentration values shows that vehicle A, B, C and E are all below the emission limit of 4.00g/kWh, but close to the emission limit, especially vehicle E is almost beyond the emission limit, as shown in figure 2. The emission concentration of vehicle D is 6.03g/kWh, which exceeds the emission limit and does not meet the in-use consistency requirements. Among the five vehicles, only vehicle C has the lowest NOx emission concentration. According to vehicle information, vehicle C has the longest service time and the largest mileage. Urea is used strictly according to the regulations, and regular maintenance is done. The service time of vehicle B and E is within half a year, and the mileage is low, the overall vehicle condition is similar to that of new vehicles, but the NOx emission concentration is higher than that of vehicles C. On the one hand, because there are differences in the effect of aftertreatment devices between different vehicle brands [17]; On the other hand, the removal effect of SCR on NOx is better than that of EGR.

![Figure 2. Comparison of NO\textsubscript{X} emission concentration of PEMS test.](image)

According to HJ857-2017 regulations, the NO\textsubscript{X} emission concentration of heavy-duty diesel vehicles should meet the requirements of the overall emission limit, and at the same time the NOx emission concentration data points less than 900 ppm in the whole test process account for 95% or more. According to the statistics of NOx emission concentration data points of 5 vehicles in the test process, as shown in table 2, the NO\textsubscript{X} emission concentration data points meeting the requirements (lower than 900ppm) of vehicle A, B, C and D account for 95% or more, while vehicle E does not meet the requirements.

**Table 2.** Statistics on the proportion of data points with NO\textsubscript{X} emission concentrations of PEMS test lower than 900ppm

| No. | Percentage of data below the limit |
|-----|----------------------------------|
| A   | 100%                             |
| B   | 100%                             |
| C   | 100%                             |
| D   | 99%                              |
| E   | 94%                              |

In order to display the NOx emission process data of five vehicles well, the scatter plot of the
process data is compared with the emission limit, as shown in figure 3. Before the test time of 3000-4000s, it is the urban road section, and then it is the suburban and highway road section. In fact, the speed control of each vehicle cannot be guaranteed to be exactly the same, so there is a small difference in the test time, which is within the normal test error range. NOx emissions of vehicles A, B, C and D tend to decrease after driving on suburban and highway sections, because the speed of suburban and highway sections is relatively high, the emission temperature also increases accordingly, and the increase of exhaust temperature improves the catalytic conversion efficiency of SCR system [7]. However, the NOx emission of vehicle E did not change significantly after driving in suburban and highway sections, and the whole emission was higher, because vehicle E used EGR technology to remove NOx, compared with SCR, EGR had lower NOx removal efficiency and relatively backward technology.

(a) NOX emission concentration of vehicle A during PEMS test.

(b) NOX emission concentration of vehicle B during PEMS test.
Overall analysis, vehicle A, B, C NOx emissions meet the requirements of in-use consistency, but the emission concentration is close to the emission limit, while vehicle D, E do not meet the requirements. From this point of view, the status of NOx emission of China V heavy-duty diesel...
vehicles in Shenzhen is not optimistic, and corresponding management measures should be taken to strengthen the standardized use of vehicle urea in diesel vehicles, and regular maintenance of after-treatment devices should be carried out.

2) In-service consistency analysis based on LugDown test. According to GB3847-2018, nitrogen oxides at 80% VelMaxHP point of five vehicles are compared with emission limits, as shown in figure 4. The standard gives two limits, the limit a is 1500ppm, and the limit b is 900ppm. At present, Shenzhen adopts the limit a. The test results of the five vehicles are far less than the limit value a and also less than the limit value b, which is quite different from the in-service consistency results of the PEMS test; Among the five vehicles, vehicle E has the largest emission and vehicle A has the smallest emission, which is also quite different from the PEMS test results.

![Figure 4](image-url). Comparison of NO\textsubscript{X} emission concentration of LugDown test.

3.2. Comparative Analysis of the Results of Different Test Method
This section compares the LugDown and PEMS test NOx emission data by using the box plot, and then analyzes the differences between the two test methods. As shown in figure 5, the box plots of the LugDown and PEMS test NOx emission data of five vehicles are compared and analyzed. The average value of the LugDown test of five vehicles is 138-259 ppm, and the average value of the PEMS test is 163-359 ppm. The median for the LugDown test is 98-174 ppm and the median for the PEMS test is 131-315 ppm. The test results of PEMS are significantly higher than those of LugDown, and the test results of vehicles D and E were higher than those of vehicle A, B and C, which was consistent with the previous analysis that vehicles D and E don't meet the emission limits of in-use consistency.

The statistical results of the two test methods for five vehicles are compared, as shown in table 3. The data of two test method by vehicle A, B and C are similar, the difference of average value is 14\% -18\% and the difference of median value is 1\% -63\%. The data of the two test methods for vehicle D and E are quite different, the average difference is 32\% -63\%, the median difference is 81\% -127\%. Based on the above analysis results, LugDown test can not reflect the vehicle emissions of road conditions, especially for diesel vehicles with high NOx emissions, the two test methods have great differences.
Figure 5. Comparison of NO\textsubscript{X} emission concentration in box plot tested by PEMS and LugDown.

Table 3. Statistics on the difference of NO\textsubscript{X} emission concentration between PEMS and LugDown test %.

| Item        | Vehicle A | Vehicle B | Vehicle C | Vehicle D | Vehicle E |
|-------------|-----------|-----------|-----------|-----------|-----------|
| Upper Edge  | 18        | 5         | 39        | 8         | 113       |
| Upper Quartile | 7        | 26        | 31        | 8         | 78        |
| Average Value | 18       | 17        | 14        | 32        | 63        |
| Median      | 63        | 2         | 1         | 127       | 81        |
| Lower Quartile | 11       | 42        | 53        | 515       | 25        |

3.3. Analysis of Particulate Matter Emission Characteristic

The particulate matter emission data of five vehicles are compared and analyzed with the average value of the test process. As shown in figure 6, it is found that the particulate matter emissions of vehicle B and C were significantly higher than those of other vehicles, and the particulate removal effect of vehicle E was the best. In addition, compare the process data, as shown in figure 7, the comparison of the emission concentration is consistent with the comparison of the average value; the comparison of the urban, suburban, and highway emission characteristics of the process data reveals the following characteristics:

1) The high PM emissions from vehicles A and B mainly occur in high-speed sections, and the high emission values appear only near 1000s. While in the urban and suburban sections with relatively low speed, the PM emission is almost zero;

2) Vehicle C and D PM emissions are relatively scattered. The emissions in highway sections (vehicle C is more prominent) are relatively high, but there are also certain concentrations of PM emissions in urban and suburban sections (vehicle D is more prominent);

3) The particulate emission of vehicle E is low in the whole process.

According to the technical status of the vehicles, the emission characteristics are analyzed. It is found that vehicles A, B and E are equipped with DPF, which had a short service time and a short driving mileage, but the average PM emission of vehicle B was 113 times as much as that of vehicle E. The peak value of PM emission of vehicle A and B on the highway section should be caused by the regeneration of DPF, which is easy to accumulate PM in DPF due to high speed and high engine power under this condition [18]. Vehicle C and D are not equipped with DPF, have long service time
and large driving mileage, and mainly use internal purification technology to remove PM, but the average difference of PM emission is still more than 6 times. PM emission characteristics are obviously different from vehicle A, B and E. There is a higher concentration of PM emissions in the whole driving process, but the concentration of PM is higher at higher speed and higher power conditions. It should be pointed out that only vehicle D engine is imported engine, even without DPF, PM emissions are still lower than vehicle A, B, C. There is a big gap between the domestic engine and the imported engine in the internal purification technology.

Figure 6. Comparison of PM emission average concentration of PEMS test.

(a) PM emission concentration of vehicle A during PEMS test.
(b) PM emission concentration of vehicle B during PEMS test.

(c) PM emission concentration of vehicle C during PEMS test.

(d) PM emission concentration of vehicle D during PEMS test.
Figure 7. Comparison of PM emission concentration during PEMS test.

4. Conclusions
Based on the comparison and analysis of the in-use consistency of CO and NOx emissions, PM characteristics and the results of different test methods to five vehicles, some conclusions are drawn:

1) Based on the analysis of HJ857-2017, the CO emission concentration of five vehicles is far below the emission limit, and the NOx emission of two vehicles exceeds the in-use consistency emission limit, because they don't have SCR aftertreatment, or SCR lacks maintenance and aging is serious. Based on the analysis of GB3847-2018, the NOx emission of five vehicles is far below the emission limit, and the results of the two test methods are quite different.

2) The NOx emission results of the two test methods are analyzed. The results of the two test methods are close to each other for the vehicles with lower NOx emission. For vehicles with higher NOx emissions, the LugDown test results are significantly lower than those of PEMS.

According to the characteristic of PM of five vehicles, the DPF can effectively control the particulate emission, but the efficiency of removing particulate of DPF of different vehicles is quite different under the road conditions;

Based on the analysis of the above three aspects, LugDown test can not well reflect the vehicle emissions under the road conditions, and the emission status of in-use China V heavy-duty diesel vehicles in Shenzhen under the road conditions is not optimistic. It is necessary to adopt more stringent emission limits and strengthen the supervision of in-use diesel vehicle emissions.

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