Analysis of Real-World Fuel Consumption Characteristics of Heavy-Duty Commercial Diesel Vehicle Based on OBD Method

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Abstract. In this paper, heavy-duty commercial diesel vehicles were selected for the actual road, vehicle emission test system (PEMS), C-WTVC and CATC test, and each test was connected to the OBD remote monitoring equipment. Through PEMS test and C-WTVC test, the instantaneous fuel consumption data and carbon balance fuel consumption data of OBD remote monitoring equipment are compared within 10%, which proves that OBD remote monitoring has good accuracy. The fuel consumption of the actual road test normalized to CATC is 10.8%-88.0% higher than that of the ministry of industry and information technology type certification, with an average value of 45.1%. The fuel consumption under the normalized C-WTVC condition is 10.1%~76.6% higher than that under the type approval of the ministry of industry and information technology, with an average value of 40.0% 23.9%. This difference is relatively smaller than that under the normalized to CATC. It is of great significance to correctly guide the development and calibration of vehicles and promote the research and application of vehicle energy conservation and emission reduction technologies suitable for China’s traffic characteristics and actual use characteristics.

1. Introduction

The vehicle fuel consumption data corresponding to the existing fuel consumption management standards in China are based on the fuel consumption of the certified working conditions measured by the NEDC (New European Driving Cycle) cycle. However, the existing research results show that there is a difference between the actual road fuel consumption of the vehicle and the fuel consumption of the certified working condition. According to the ICCT research report, the difference in fuel consumption between actual roads and type certification mainly includes three reasons. First, the test conditions and operating procedures for light vehicle type certification are often optimized for fuel economy relative to actual road conditions. Second, more and more vehicles use advanced fuel-saving technologies (such as start-stop technology). The fuel economy rate under the certification test conditions is higher than the actual effect; in addition, the fuel consumption is significantly increased due to traffic congestion, air conditioning use and low temperature environment during the actual driving process [1-3].

On the basis of the vehicle tester, Huang et al. [4] obtained an average fuel consumption of 17.8L per 100 kilometers of the actual road of a heavy-duty diesel vehicle in the urban area of Shanghai. When the vehicle accelerates, the fuel consumption reaches 2.0 times of the actual road. When the vehicle rapid accelerates, the fuel consumption reaches 2.8 times of the actual road. Huang et al. [5] obtained the fuel consumption of loading vehicle is about 1.6 to 3.2 times to no-load during the constant speed and acceleration driving on the basis of the actual road test of heavy-duty diesel vehicles. Yao et al. [6]
pointed out that the average fuel consumption of a heavy-duty diesel vehicle at variable speed per 100 km is 1.08 to 1.24 times at a constant speed. It can be seen that factors such as acceleration and deceleration, idle speed, vehicle load and driver’s driving behavior caused by complex road conditions can cause the actual road fuel consumption of heavy-duty diesel vehicles to differ greatly from the fuel consumption of certified working conditions.

In order to achieve effective detection of vehicle pollution emissions and fuel consumption, on-board diagnostics (OBD) has developed rapidly in recent years. In the early stage, the OBD-based test data was compared with the PEMS standard test data to verify the correctness and accuracy of the OBD acquisition equipment and experimental design scheme [7-8].

This paper introduces the “Chinese Working Conditions” (CATA) that is closer to China’s actual roads for experimental design. Through research, it is found that the characteristics of Chinese working conditions are very consistent with the actual collected data. Select heavy-duty commercial diesel vehicles for actual road testing, PEMS testing, C-WTVC testing, and CATC drum testing. Connect OBD for each test. Firstly, the difference between the instantaneous fuel consumption data and the carbon balance fuel consumption data collected by the OBD is compared and verified, and the accuracy of the oil consumption of the OBD method is verified. According to the micro-operational modal method, the actual road fuel consumption measured by OBD is normalized to the fuel consumption of the certified working condition, and the normalized result is compared.

2. Experimental Methods and Data Processing

2.1. Test Overview

The test sample of this study is 4 brand-name national five heavy-duty diesel vehicles. The specific parameters of the vehicle are shown in table 1.

The vehicle is used to carry out the emission test of the OBD-based remote actual road, the vehicle road PEMS test, and the drum test. The specific test equipment list and test conditions are shown in table 2.

The test vehicle is in full load state when the actual road test, PEMS test and drum test are carried out. The full load state can objectively reflect the state of the vehicle in actual use.

| Total vehicle quality | Rated load | Shift mode | Maximum speed | Type | Fuel  |
|-----------------------|------------|------------|----------------|------|-------|
| 18000kg               | 9995kg     | Manual, 7 shifts | 105km/h | N2   | Diesel |

| Number of cylinders and arrangement | Emission Standards | Engine displacement | Rated power /rotating speed | Maximum net power | Idle speed |
|-------------------------------------|---------------------|---------------------|-----------------------------|-------------------|------------|
| 4-cylinder inline                   | National 5 / Euro 5 | 4.46L               | 134kW/2300r/min             | 129kW             | 700r/min   |

| Testing method          | Actual road remote monitoring          | PEMS test                  | Drum discharge test         |
|-------------------------|----------------------------------------|-----------------------------|-----------------------------|
| Test Equipment          | OBD-III vehicle remote monitoring equipment [6] | HORIBA OBS-ONE Vehicle Gas Emissions Testing Equipment | Analysis and detection of gaseous pollutants MEXA-7200DTR |
| Test condition          | Actual road operation                   | Test according to HJ857-2017 test requirements | Test according to GB 17691-2018 test requirements |

2.2. Data Processing Methods

In this paper, the OBD method is used to obtain the diesel engine operating conditions, engine parameter information and instantaneous fuel consumption information through the OBD data remote acquisition
terminal, and the transient fuel consumption is processed by the micro-operation mode method. The impact of actual road operating conditions on fuel consumption. The fuel consumption difference between the actual road and vehicle drum test conditions were analyzed.

2.2.1. Microscopic Operation Mode Division. In this study, the v-VSP micro-modal modal method is used to refer to the VSPBin condition of the Motor Vehicle Emission Simulator (MOVES) to determine the v-VSP micro-modal statistical interval. Power, the value of which is related to speed and acceleration. The calculation formula of VSP is shown in equation (1).

\[ VSP = v(1.1a + 0.132) + 0.000302v^2 \]  

where VSP is the engine specific power (kW/t); v is the vehicle travel speed (m/s); a is the vehicle instantaneous acceleration (m/s²).

According to the VSP Bin division rule of the heavy-duty vehicle of MOVES, according to the running state of the vehicle (deceleration, idle speed, acceleration and uniform speed) and instantaneous VSP, it is determined that each operating condition point of the vehicle belongs to the VSP Bin. Among them, the operating state of the vehicle is divided into 5 speed range: deceleration, idle speed, 0-40 km/h, 40-80 km/h and higher than 80 km/h; VSP division interval from \( \leq -8 \) kW/t, the increment is 2, increased to 12 kW/t or more, a total of 12 intervals. In this way, the vehicle operating state and the VSP joint distribution determine that the VSP Bin is 38 intervals, that is, 38 micro operating conditions. See the table below. Bin0 and Bin1 represent the deceleration and idle speed ranges respectively, Bin2-13 is the low speed (less than 40 km/h) interval, Bin14-25 is the medium speed (40-80 km/h) interval, and Bin26-37 is the high speed (greater than 80 km/h). Interval, see table 3.

| VSP (kW/t) | Acceleration a (m/s²) | Instantaneous speed v/(km/h) |
|------------|----------------------|-----------------------------|
|            | a < -0.89            | v < 1.6                     |
| VSP ≤ -8   |                      | 1.6 ≤ v < 40                |
| -8 < VSP ≤ -6 |                   | 40 ≤ v < 80                 |
| -6 < VSP ≤ -4 |                  | V ≥ 80                      |
| -4 < VSP ≤ -2 |                  |                             |
| -2 < VSP ≤ 0 |                  |                             |
| 0 < VSP ≤ 2 |                  |                             |
| 2 < VSP ≤ 4 |                  |                             |
| 4 < VSP ≤ 6 |                  |                             |
| 6 < VSP ≤ 8 |                  |                             |
| 8 < VSP ≤ 10|                  |                             |
| 10 < VSP ≤ 12|                |                             |
| VSP > 12   | Bin0 brake          | Bin1 Idle speed             |
|            | Bin2                | Bin3                        |
|            | Bin4                | Bin5                        |
|            | Bin6                | Bin7                        |
|            | Bin8                | Bin9                        |
|            | Bin10               | Bin11                       |
|            | Bin12               | Bin13                       |
|            | Bin14               | Bin15                       |
|            | Bin16               | Bin17                       |
|            | Bin18               | Bin19                       |
|            | Bin20               | Bin21                       |
|            | Bin22               | Bin24                       |
|            | Bin23               | Bin25                       |
|            | Bin24               | Bin26                       |
|            | Bin25               | Bin27                       |
|            | Bin26               | Bin28                       |
|            | Bin27               | Bin29                       |
|            | Bin28               | Bin30                       |
|            | Bin29               | Bin31                       |
|            | Bin30               | Bin32                       |
|            | Bin31               | Bin33                       |
|            | Bin32               | Bin34                       |
|            | Bin33               | Bin35                       |
|            | Bin34               | Bin36                       |
|            | Bin35               | Bin37                       |

2.2.2. Normalization Calculation of Fuel Consumption Based on Microscopic Operation Mode. According to the micro-operation mode division method described in section 2.2.1, using the distribution of v-VSP, the transient fuel consumption data of the experimental vehicle per second is divided into the corresponding micro-running Bin, and all transient operating points in each Bin are calculated. The average fuel consumption (L/s), the formula is shown in equation (2):

\[ \overline{FR_{i,j}} = \frac{1}{T_{i,j}} \sum_{t=1}^{T_{i,j}} FR_{i,j,t} \]  

where \( i, j, t \) represent the number of the test heavy-duty vehicle, the micro-operation mode number and time, respectively; \( FR_{i,j,t} \) is the average fuel consumption rate (L/s) of the heavy-duty vehicle \( i \) under the micro-modality \( j \) at \( t \) second; \( FR_{i,j,t} \) is The transient fuel consumption (L/s) of the heavy-duty vehicle \( i \) in the micro-operation mode \( j \) at \( t \) seconds; \( T_{i,j} \) is the total number of seconds (s) of the light-duty vehicle \( i \) in the micro-running mode \( j \).

According to the average fuel consumption of each microscopic operation mode and the time distribution of each microscopic Bin in a given operating condition, the fuel consumption of the vehicle under a given working condition is calculated. The calculation formula is shown in equation (3).

\[
FC_{i,\theta} = \frac{100 \times 3600 \times \sum_{j=\theta}^{\theta+\phi} (FR_{i,j} \times P_j)}{\overline{\nu}} 
\]

where, \( FC_{i,\theta} \) for a heavy-duty vehicle \( i \) normalized to a fuel consumption of 100 km in a given working condition (L/100 km); \( P_j \) is the time proportion of the micro-operational mode \( j \) in the given working condition; \( \overline{\nu} \) is average speed at this working condition (km/h).

3. Analysis of Test Results

3.1. Comparison of OBD Fuel Consumption and Carbon Balance Fuel Consumption

In this study, a PEMS test was carried out on a heavy-duty diesel vehicle on the actual road, and the vehicle OBD data was collected synchronously. Figure 1 is a comparison of the instantaneous results of carbon balance fuel consumption and OBD fuel consumption taken from a PEMS test result for a period of time. It can be seen from figure 1 that OBD fuel consumption and carbon balance fuel consumption change trends are the same, and OBD fuel consumption is slightly higher than carbon balance fuel consumption. The main reason may be that the production of particulate matter in heavy-duty diesel vehicles is compared [10], resulting in carbon balance fuel consumption lower than OBD. Measured fuel consumption. At the same time, three C-WTVC and one CATC working conditions were tested on a heavy-duty diesel vehicle in the drum laboratory, and the OBD fuel consumption data was collected simultaneously. Figure 2 shows the instantaneous results of carbon balance fuel consumption and OBD fuel consumption for C-WTVC operating conditions. It can be seen from figure 2 that the OBD fuel consumption and the laboratory carbon balance fuel consumption are in good agreement in the first 1000s. After 1000s, the OBD fuel consumption is slightly higher than the carbon balance fuel consumption. It can be seen that the laboratory drum test also has the effect of particle formation. Figure 3 is a linear regression fit of OBD fuel consumption and carbon balance fuel consumption for PEMS test and C-WTVC working condition test. The fitting R2 results are 0.8609 and 0.9477, respectively. The OBD fuel consumption and carbon balance of PEMS test and C-WTVC condition can be seen. Fuel consumption has a high degree of coincidence to some extent [11].

![Figure 1](image-url). Comparison of instantaneous OBD fuel consumption and carbon balance fuel consumption in PEMS test.
Figure 2. Comparison of instantaneous OBD fuel consumption and carbon balance fuel consumption under C-WTVC condition.

Figure 3. Linear regression fit of OBD fuel consumption and carbon balance fuel consumption.

3.2. Actual Road Fuel Consumption

Since the actual road, PEMS test, C-WTVC and CATC operating parameters (speed time curve, load, etc.) are different, the instantaneous fuel consumption data cannot be directly compared, so this paper will test the actual road operation, PEMS test, C-WTVC drum test and CATC drum test four different operating conditions according to the micro-operation mode time proportion, see figure 4. After time division of C-WTVC and CATC, the working conditions are mostly concentrated in the low and medium speed stages (C-WTVC time ratio is 36.35%, 34.02%; CATC is 42.25% and 32.30% respectively), and CATC high speed ratio (7.73%) is less than C-WTVC (15.9%); PEMS is mostly concentrated in the medium and high speed stage (54.52%, 31.01%, respectively); the actual road operation is concentrated in the medium speed stage (85.15%), and the high speed stage accounts for very little. Since the CATC high speed accounted for less than the C-WTVC, it can be seen that the CATC is closer to the actual road fuel consumption [12].

The actual roads of 4 vehicles (A, B, C, D, respectively) were run for 3 days, and were normalized to C-WTVC and CATC fuel consumption according to the v-VSP micro-operation mode. The result of fuel consumption is shown in figure 5. In the four cars, the A and B cars are the same car, the C car and the D car are the same car. The A and B cars are normalized to the CATC fuel consumption is 24.7±2.5L/100km, normalized to C-WTVC fuel consumption is 24.1 ± 2.4L/100 km; C car and D car are the same car, normalized to CATC fuel consumption is 40.0 ± 7.0L/100 km, normalized to C-WTVC. The fuel consumption is 38.2 ± 6.6L/100 km. It can be seen that the fuel consumption data of the actual road operation is normalized to the CATC fuel consumption is higher than the normalized to C-WTVC fuel consumption, mainly because the CATC has a lower average running speed than the C-WTVC (respectively 33.70 km/h, 41.00 km/h), a larger proportion of acceleration and deceleration conditions (2.67%, 1.95%, respectively), and the speed of China’s working conditions is mainly distributed in the low and medium speed ranges, and the speed is distributed above 80 km/h. The proportion is only 7.73%,
while the proportion of C-WTVC distributed above 80km/h is as high as 15.9%. The actual road operating conditions are normalized to the fuel consumption of CATC, which is 10.8%-88.0% higher than that of the Ministry of Industry. The average value is 45.1%. The actual road operating conditions are normalized to the C-WTVC operating conditions. The fuel consumption is 10.1%-76.6% higher than that of the Ministry of Industry. The average value is 40.0±23.9%. This difference is relatively small compared with the normalized CATC. This is due to the fact that some conditions of the vehicle are optimized in the type certification test. This shows that China’s working conditions are highly close to the actual operation of the vehicle.

![Time distribution ratio graph](image)

**Figure 4.** Micro-modal division time ratio of different operating conditions.

![Normalized FC graph](image)

**Figure 5.** Results of normalization of fuel consumption of four heavy-duty diesel vehicles.

4. Conclusion

(1) The difference between OBD fuel consumption and carbon balance fuel consumption of C-WTVC, CATC and PEMS is within ±10%; the linear regression fit R² of instantaneous OBD fuel consumption and instantaneous carbon equilibrium fuel consumption in PEMS test and C-WTVC test is 0.8609 and 0.9477 respectively, it can be seen that OBD fuel consumption and carbon balance fuel consumption have a high degree of coincidence to some extent, further illustrating the credibility of the OBD fuel consumption test method.

(2) The fuel consumption of the actual road test normalized to CATC is 10.8%-88.0% higher than that of the Ministry of Industry. The average value is 45.1%. The fuel consumption normalized to C-WTVC is 10.1%-76.6% higher than that of the Ministry of Industry. The average value is 40.0±23.9%. This difference is relatively small compared with the normalized CATC. It shows that the working condition of China is highly close to the actual operation of the vehicle, and it is of great significance to correctly guide the research and application of vehicle development and calibration, and promote the
research and application of vehicle energy-saving and emission reduction technologies applicable to China’s traffic characteristics and actual use characteristics. It lays the foundation for the actual road monitoring of OBD in the future instead of the legal type certification test.

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