Influence of driving conditions on the emission characteristics of China Ⅵ heavy-duty vehicles

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Abstract. In order to study the feasibility of the low load cycle (LLC) condition applied to China's heavy-duty trucks, this paper selects a China VI heavy-duty trucks with 100% load to study the pollutant emission and driving condition characteristics of LLC, C-WTVC and CHTC-HT on chassis dynamometer. Vehicle specific power (VSP) is adopted as analysis method. The results show that the emission of pollutants (NOX, PN, CO2) under LLC cycle is higher than that under C-WTVC and CHTC-HT. the NOx emission and PN emission of the LLC are about 1 order of magnitude and 3 orders of magnitude higher than those under C-WTVC and CHTC-HT respectively. Compared with C-WTVC and CHTC-HT, CO2 emission of the LLC has the highest total emission performance, while the average emission rate of each VSP interval has the lowest performance, about 3.7g/s.

Keywords. Low Load Cycle; Emission characteristic; VSP

1. Introduction

As a major contributor to mobile pollution sources, heavy-duty vehicles have always been a key target of supervision by environmental protection agencies. In recent years, as the number of heavy-duty vehicle continues to increase, the state has issued more and more policies and standards for the emission controls of heavy-duty vehicle. It can be seen that the control of pollutant emissions from heavy-duty vehicles is still the focus of air pollution control. The International Council on Clean Transportation (ICCT) has been tracking and recording heavy-duty vehicles emission on the road for a long time. The results show that NOx emission in urban areas (0-25 MPH) is about 7 times of the EPA2010 limit. The NOx emission in the suburban area (25-50 MPH) is about 3 times of the EPA2010 limit, and the NOx emission in the high-speed area (>50 MPH) is almost the same as the EPA2010 limit. The above shows that the current U.S. heavy-duty vehicle emission supervision methods cannot effectively control pollutant emissions under urban and suburban driving conditions. Research shows that when the engine operates under low load conditions, the exhaust temperature is low, and the performance of the aftertreatment system is poor, which causes the vehicle's emission under this condition to exceed the standard. It shows that the emission test requirements for heavy-duty vehicles under low load conditions are omitted in the existing engine test cycles and the actual road emission test procedure for the vehicle. Therefore, the Southwest Research Institute developed and formulated a supplementary test cycle for heavy-duty engines and vehicles-LLC (Low Load Cycle) to control the pollutant emissions of heavy-duty vehicles under low load conditions.

Based on a chassis dynamometer, the difference in emission characteristic between LLC and C-WTVC of current heavy-duty vehicles in-use test cycle and CHTC-HT of China automobile test cycle is researched to provide pre-research for the feasibility of the LLC in China [1,2]. Using the Vehicle Specific Power (VSP) analysis method ,the driving characteristics and emission characteristics of the vehicle are researched under three test cycles [3-10].

2. Testing program

2.1 Test vehicle

A chassis dynamometer exhaust pollutant measurement test was carried out on a heavy-duty China VI truck with 100% load condition. The basic information of the vehicle and engine is shown in Table 1.

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Table 1. Vehicle and engine parameters

Vehicle / Engine	Parameters
GVWR (kg)	16000
Curb weight (kg)	7875
Fule type	Diesel
Engine displacement (L)	3.8
After-treatment type	DOC+DPF+SCR
Rated power/speed (kW/(r/min))	140/2600
Maximum net power (kW/(r/min))	137/2600

2.2 Test equipment and cycles

The test was conducted in accordance with GB/T 27840-2011 "Method for Measuring Fuel Consumption of Heavy Commercial Vehicles". The HORIBA EXA-7200DTR full-flow diluted exhaust gas analyzer was used on the chassis dynamometer for pollutant emissions test. When the coolant temperature reached above 70°C, the CO_2, NO_X and PN pollutants were sampled and analyzed based on the C-WTVC, CHTC-HT and LLC under warm state, and the sampling frequency was 1 Hz. The curves of three test cycles are shown in Figure 1 to Figure 3, and the statistical characteristics of the operating conditions are shown in Table 2. During the test, the average ambient temperature was about 24°C, and the average atmospheric pressure was about 102.5kpa.

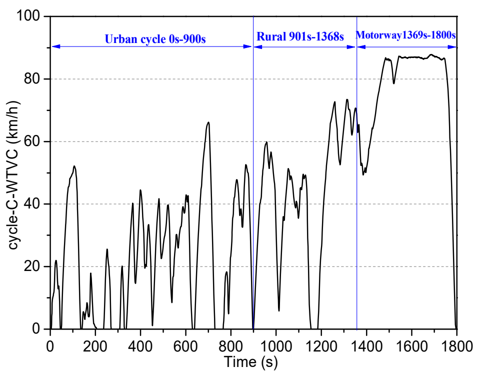

Figure 1 Hevay-duty commercial vehicles test cycle (C-WTVC).

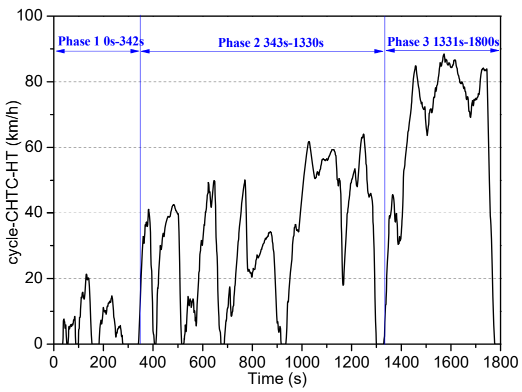

Figure 2 China Heavy-duty commercial vehicles test cycle (CHTC-HT).

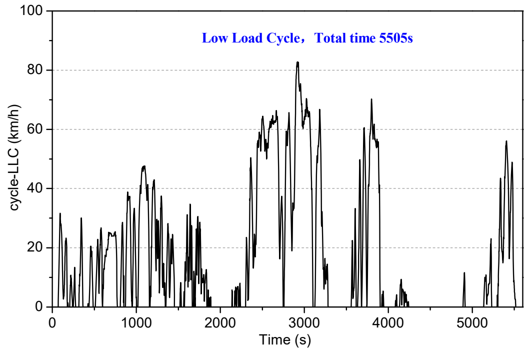

Figure 3 Low Load Cycle (LLC).

Table 2. Driving characteristic statistics

Parameters	C-WTVC	CHTC-HT	LLC
Total time (s)	1800	1800	5516
Idle time (s)	107	171	1943
Total distance (km)	20.31	17.23	24.58
Maximum speed (km/h)	86.15	85.91	80.41
Average speed (km/h)	40.62	34.46	16.04
Maximum acceleration (m/s^2)	1.12	0.99	1.11
Maximum deceleration (m/s^2)	1.17	1.40	1.87
Acceleration ratio (%)	35.4	30.6	22.9
Deceleration ratio (%)	27.5	22.9	19.4
Constant speed ratio (%)	31.2	37.0	22.4
Idle speed ratio (%)	5.9	9.5	35.2

Comparing and analyzing the three test cycle curves and corresponding data statistics results, it can be seen that the driving time of the LLC is longer than that of the C-WTVC and CHTC-HT , and the total time is up to 5516s.The driving characteristics of the LLC show that the average vehicle speed and the ratio of acceleration and deceleration are low, while the idling speed ratio is relatively high, which is about 4-6 times that of the C-WTVC and CHTC-HT. The characteristics of the data show that LLC mainly covers low-speed and low-load driving conditions of heavy-duty vehicles, which focus on evaluating the driving characteristics and emission characteristics of vehicles under low-speed and low-load conditions. It can be seen that LLC is of great significance to the future emission supervision of heavy-duty vehicles under low-speed and low-load conditions.

2.3 Data Processing

Vehicle specific power (VSP) is the output power that characterizes the engine to overcome the rolling resistance, air resistance, slope resistance and acceleration resistance of the vehicle during driving. It is based on speed and comprehensively considers the impact of wind resistance, road gradient, acceleration, environmental conditions and other factors on vehicle emission during vehicle driving. Using VSP to analyze vehicle emission characteristics can not only effectively avoid the influence of vehicle load state change on emission results, but also can more truly reflect the actual road driving characteristics of the vehicle [11]. VSP is a vector variable with a direction. When VSP>0 kW/t, it means that the vehicle is in an accelerating driving condition. On the contrary, the vehicle is in a decelerating condition. When VSP=0 kW/t, it means that the ve:hicle is in an idling condition. According to the definition of VSP, calculation formula is as follows.

$$VSP = \frac{\left(F_f + F_i + F_w + F_j\right) \bullet v}{m} \quad (1)$$

$$\mathrm{VSP} = v \cdot [g \cdot f + g \cdot \sin\alpha + (1+\varepsilon) \cdot a] + 0.5\rho \frac{\tau \cdot A}{m} (v + v_m)^2 \cdot v \quad (2)$$

F_f is the rolling resistance, N; F_i is the air resistance, N; F_W is the slope resistance, N; F_j is the acceleration resistance, N; m is the gross vehicle weight, kg; v is the vehicle speed , km/h; g is the acceleration due to gravity, with a value of 9.8m/s^2; f is the coefficient of rolling resistance; α is the road gradient; ε is the quality factor, with a value of 0.1; a is the acceleration of the vehicle, m/s^2; ρ is the air density under the experimental environment, g/m^3; τ is the coefficient of air resistance, A is the windward area of the vehicle, m^2; v_m is the wind speed in the test environment, m/s.

Before the start of the test, the static measurement test of VSP parameters was carried out by barometer and densimeter according to the Appendix C standard of GB 27840-2011 "Heavy Commercial Vehicle Fuel Consumption Measurement Method". The parameters value required in Formula 2 are obtained according to the static test measurement results. The VSP parameters value are shown in Table 3.

Table 3. VSP parameters value

VSP parameters	Values
Gravitational acceleration g (m/s^2)	9.8
Rolling resistance coefficient f	0.0045
Road Gradient α	0
Quality factor ε	0.1
Ambient air density ρ (g/m^3)	1.189
Test ambient wind speed v_m (m/s)	0
Air resistance coefficient τ	0.8
Windward area A (m^2)	6.783

Substitute the results of Table 3 into Formula 2, a simplified VSP calculation formula is as follows:

$$VSP = v \cdot (1.1a + 0.044) + 0.002v^3 \quad (3)$$

Formula 3 is used to calculate the instantaneous VSP values under three test cycles, and the interval division method is used to cluster the VSP data. Using 2kW/t as the unit to divide the VSP interval, it is found that the operating conditions points of the three tests cycles are mainly concentrated in the range of VSP∈[-8,8] kW/t, and the result is shown in Figure 4.

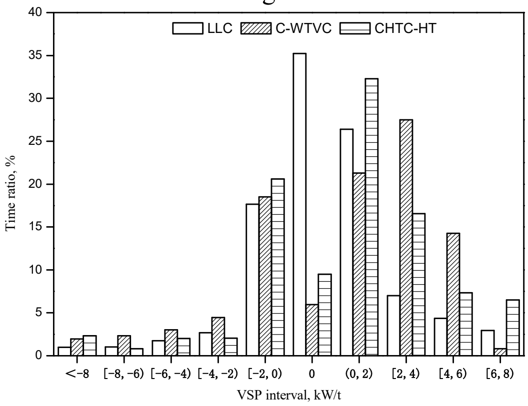

Figure 4. VSP interval distribution.

Figure 4 shows the distribution characteristics of the VSP intervals under three test cycles. The results shown are basically consistent with the statistical results of the driving conditions in Table 2. The figure 4 shows that the driving time of VSP>0 kW/t interval is larger than that of the VSP<0 kW/t interval in the three test cycles, which the vehicle acceleration ratio is higher. The VSP intervals distribution of the LLC are a normal distribution. The driving time ratio in the VSP∈[- 2,2] kW/t is as high as 80%, of which the driving time ratio of VSP=0 (idling condition) accounts for the largest proportion, 35.2%. In the C-WTVC, the driving time ratio of VSP∈[-2,2] kW/t accounts for about 45.7%, and the driving time ratio of VSP ∈ [-2, 2] kW/t accounts for about 62.4% in the CHTC-HT. The comparative analysis results show that there are differences in the driving time ratio of low speed and low load conditions under three test cycles, and the LLC is more inclined to the low-speed and low-load test requirements.

3. Test results and analysis

3.1 Vehicle driving characteristics analysis

Figure 5 to Figure 7 show the driving characteristics of the vehicle under three test cycles. The analysis results show that the vehicle has more operating points and a wide distribution range under low speed conditions, and fewer operating points under high speed operating conditions. The acceleration is mainly concentrated in the range of -1m/s^2~1m/s^2. Detailed analysis is shown below.

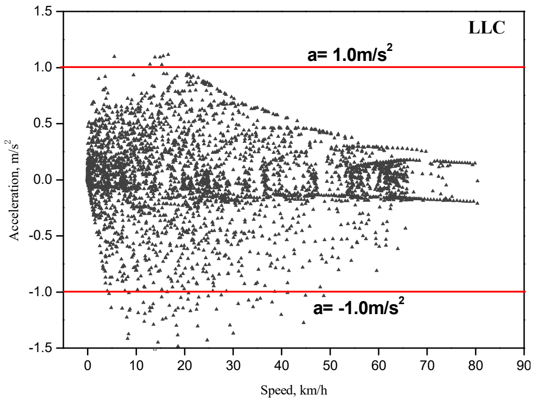

Figure 5. LLC characteristics.

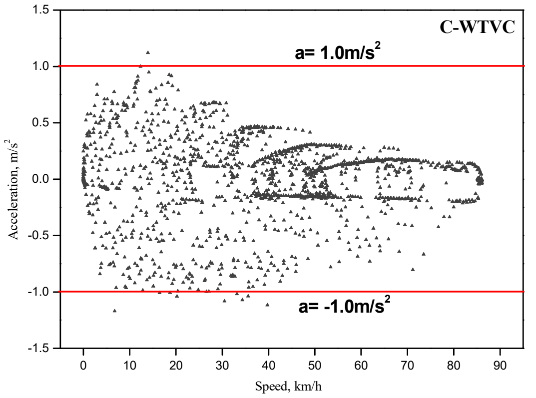

Figure 6. C-WTVC characteristics.

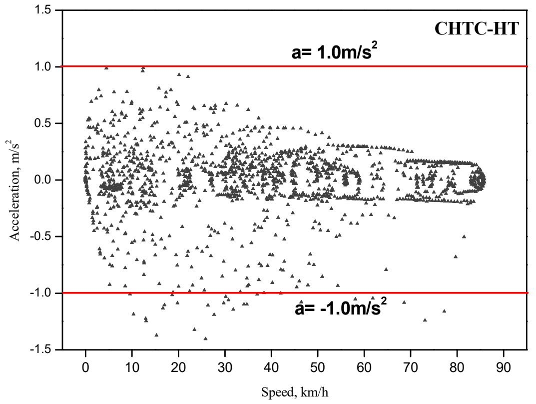

Figure 7. CHTC-HT characteristics.

Figure 5 shows that the operating points concentrate in the range of V<50km/h are about 88% in the LLC, and the low speed driving time is long, which reflects that the LLC focuses on examining the low speed driving conditions. Figure 6 shows that the operating points distribution of C-WTVC are relatively scattered in the low speed, and the operating points distribute in the range of V<50km/h are about 63%, which reflects that the C-WTVC has less examination than the LLC in low speed. The CHTC-HT characteristics show that the operating points distribute in the range of V<50km/h are about 70%. Compared with the C-WTVC, CHTC-HT are more concentrated in low speed, and the distribution range is mainly concentrated in $-0.25<a<0.25m/s^2$. In summary, the three test cycles have different examination on the vehicle actual driving conditions , and the LLC most focuses on examining the low-speed driving conditions.

3.2 Pollutant emission characteristics Analysis

The average emission rate of the pollutants in each VSP interval is calculated and the pollutant emission characteristics of the vehicle are analyzed under the three test cycles. Figure 8 to Figure 10 show the distribution of NO_X, CO_2, and PN in the VSP intervals. The results are shown below.

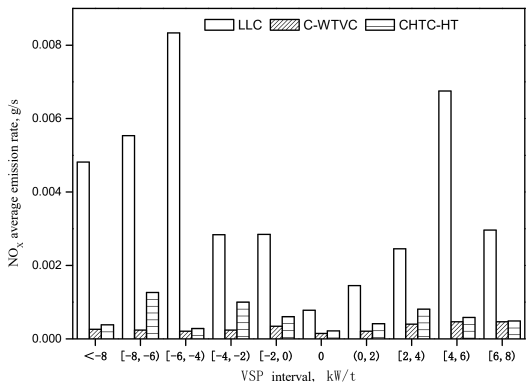

Figure 8. NO_X emission rate.

Figure 8 shows that the NO_X emission rate of the vehicle is the lowest in the three test cycles, when the VSP is equal to 0 kW/t. The main reason is that when VSP is equal to 0 kW/t, the vehicle is idle driving condition, which the engine does not work, and fuel injection is less, and pollutants emission are less. Comparative analysis rsults show that the NO_X emission rate of each VSP interval under LLC is one order of magnitude higher than that of C-WTVC and CHTC-HT, and the NO_X emission is relatively large.

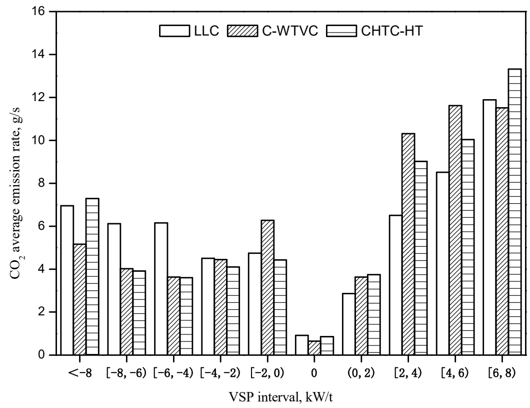

Figure 9. CO_2 emission rate.

CO_2 emission is directly related to vehicle fuel consumption. Figure 9 shows the variation of CO_2 emission with VSP. The overall performance trend of CO_2 emission decreases first and then increases with the increase of VSP in the three test cycles, which reflects the characteristics of vehicle operating conditions chang with the VSP. When VSP is equal to 0 kW/t, the fuel consumption of the vehicle is the least in idling conditions. As the absolute value of VSP continues to increase, vehicle speed , acceleration or deceleration continue to increase, resulting in an increased in fuel injection volume and CO_2 emission. Because LLC (5516s) is different from C-WTVC (1800s) and CHTC-HT (1800s) in driving total time, total CO_2 emission of LLC is largest among the three cycles, while its average emission rate is the smallest, about 3.4g/s, followed by CHTC-HT, about 5.7g/s, C-WTVC is the largest, about 7.1g/s.

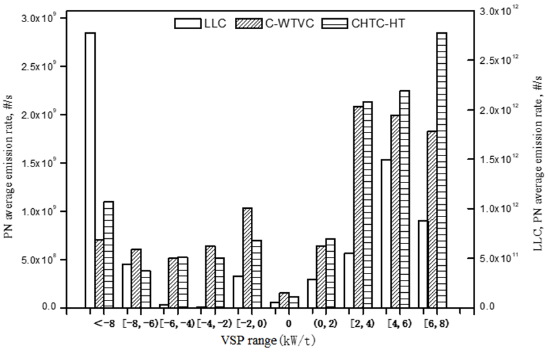

Figure 10. PN emission rate.

Figure 10 shows that PN emission is mainly concentrated in the larger distribution range of VSP, and the PN emission of VSP>0 kW/t is higher than VSP<0 kW/t. Comparative analysis resulits show that the PN emission of the LLC in each VSP interval is about 3 orders of magnitude higher than C-WTVC and CHTC-HT. The PN emission of LLC in the VSP<-8 kW/t interval is the highest among the three cycles, about 1.50E+14 #/s. It is because there are more rapid acceleration and deceleration conditions when the VSP is large, resulting in the local concentration of mixed gas in the cylinder, and the PN emission increases. In addition, the longer vehicle driving time in the LLC leads to the high PN emission.

4. Conclusion

A heavy-duty China VI truck is selected to carry out the vehicle driving condition points distribution characteristics and emission characteristics study of LLC and C-WTVC and CHTC-HT on the chassis dynamometer method. The conclusions are as follows:

The three test cycles have different levels of examination of the low-speed and low-load conditions. The VSP interval distribution of the LLC is a normal distribution, and the driving time ratio in the VSP ∈ [-2, 2] kW/t is up to 80%, and the idling condition (VSP=0 kW/t) has the highest proportion, about 35.2%.

The test cycles have a greater impact on vehicle pollutant emissions. The comparative analysis results show that the NO_X emission of the vehicle under LLC is one order of magnitude higher than C-WTVC and CHTC-HT, and PN emission is three orders of magnitude higher than C-WTVC and CHTC-HT. Although the total amount of CO_2 emission is relatively large in the LLC, the average emission rate is the smallest, about 3.7g/s; CHTC-HT is the second, about 5.7g/s; C-WTVC is the largest, about 7.1g/s.

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