Analysis of fuel consumption and emission between C-WTVC and PEMS methods of heavy-duty vehicle

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Abstract. The chassis dynamometer and PEMS test implemented on a heavy-duty vehicle, through comparing the working condition, fuel consumption and emissions result, it showed that the engine working area in PEMS test occupy most of the working area under the engine performance curve from 1300r/min to 2500r/min at the medium load. In the C-WTVC cycle the engine usually worked below 1900r/min at medium and heavy load. Thus in PEMS test the fuel consumption and pollutant emissions are higher than them in C-WTVC test, the fuel consumption is 12.54L/100km which is 9.3% higher, the brake specific emission of NOx, PN, CO are 91.0%, 38.7%, 78.9% higher respectively. The PEMS test is more practical and convenient for heavy-duty vehicle emission test while has a poor measurement repeatability under the influence of different road conditions. The C-WTVC test cycle has a good measurement repeatability for its fixed condition.

Keywords: Heavy-duty vehicle, PEMS, C-WTVC, fuel consumption, emissions.

1. Review
The GB17691-2018 limits and measurements methods for emissions from diesel fuelled heavy-duty vehicles (China VI) has been implemented for 13 months, in which the PEMS test method specified in appendix K and the chassis dynamometer method specified in appendix L [1]. While PEMS test method is a practical road emission test method which is divided according to the time proportion of certain urban suburb and high-speed working condition usually need 3 hours at least, the vehicle pollutants collected directly by the PEMS instrument and the total emission results calculated, which including the CO, NOx, PN emissions and does not care about the heavy-duty vehicles’ fuel consumptions. The chassis dynamometer method is a bench cycle test method which simulates the urban suburb and high speed conditions with a 1800 seconds C-WTVC cycle, by using a real road coastdown test running resistance. The advantage is that the environmental condition control is good and the repeatability is high comparing to the actual driving conditions. The dyno test method focus on both the fuel consumption and the CO, NOx, THC and PN emissions. Inevitably we know there exist difference between these methods, though we did not know how much difference between them.

Most of the literatures focus on the study of one test method. In the study on the emission and test methods of vehicle compared with diesel engine bench based on CHINA VI emission standard heavy-duty vehicles by Chenlin [2], it found out that the vehicle mostly running on the constant speed condition in PEMS test, the exhaust temperature and the pullutants were more higher than that of C-
WTVC test cycle, but it did not compare the emission value difference. In the impact of driving behavior on real driving emissions from heavy-duty vehicles equipped with diesel engines by Yue Dajun [3], they concluded that the intense driving habits had significant impact on the NOx and PN emission, which made the NOx and PN emission increase at most 621.1% and 122.4% separately. Actually the driving habits influence the vehicle emission very much. In this paper, a 7.5 tons heavy-duty vehicle both on the PEMS condition and on the chassis dynamometer studied, the fuel consumption and emission difference compared.

2. Test method

2.1. C-WTVC method

In the GB/T 27840-2011 fuel consumption test methods for heavy-duty commercial vehicles, the C-WTVC driving experimental condition cycle formed by adjusting the acceleration and deceleration based on the world transient vehicle cycle, which suitable for heavy commercial vehicles burning gasoline or diesel fuel with a maximum total mass more than 3500 kg [4]. The characteristic mileage of the vehicle divided according to its application and total mass. Firstly, the vehicle’s road resistance tested on a dry, smooth line road, and the road resistance coefficients typed in the chassis dynamometer which simulating the actual road resistance. Before testing, two C-WTVC cycle run for the warming up of the vehicle. As usual, volume flow, mass flow and carbon balance method all can be used to test the fuel consumption, in this paper the carbon balance method selected. The urban suburb and high speed condition proportion are 40%, 40% and 20%. Figure 1 is the real C-WTVC condition on dynamometer.

![Figure 1. C-WTVC cycle.](image)

2.2. PEMS method

On the contrary, the PEMS is a real road condition test method which using the portable emission measurement system collect the vehicle transient pollutants and the exhaust mass flow, to calculate the overall emission. Though the working based window emission is the standard criterion, here we will only use the overall emissions as a criterion. In this PEMS test condition, the urban suburb and highway proportion are 45%, 25%, 30% and a 5% deviation is allowed. Figure 2 is the practical road running condition. The three conditions order must be one by one and the first short trip with a speed of more than 55 km/h appears is the beginning of suburban condition, and the beginning of high speed is 75 km/h. When the engine work of the test vehicle reaches at 4-7 times of WHTC circulating power, the test can be terminated.
A heavy-duty diesel vehicle tested both in PEMS and on chassis dynamometer, the vehicle parameter show as table 1. Firstly, the PEMS test performed on the road which consisted with urban road, suburb road and highway road, the total distance took 2.54 hours and 120.3km, the average vehicle speed is 47.4km/h, the average speed of the three working conditions are 25.8km/h, 46.9km/h, 76.9km/h respectively. Acceleration, deceleration, constant speed, and idle speed are occupied 20.9%, 18.6%, 54.5% and 5.9% respectively, the deceleration condition took up most of the time. Figure 3 is the route in Yancheng city. Secondly, the chassis dynamometer test performed on the bench for three complete C-WTVC cycle, one cycle lasts 1800 seconds. The total distance of urban, suburb and highway are 60.0km, the combined fuel consumption and emission calculated by the formula (1) (2) as follws.

### Table 1. Vehicle parameters.

| Name               | Parameter                                |
|--------------------|------------------------------------------|
| Vehicle Type       | N2                                       |
| Total Mass (kg)    | 4495                                     |
| Engine Type        | F2.8NS6B156                              |
| Engine Displacement (L) | 2.78                                   |
| Rated power/speed (kW/r/min) | 115/2900                     |
| Maximum Torque/speed (N.m/min) | 450/1500-2400            |
| Emission Stage     | China VI                                 |
| Aftertreatment Type| DOC+DPF+SCR+ASC                          |

Figure 2. PEMS running condition.

Figure 3. PEMS running route.
\[ F_C = F_U \times f_1 + F_S \times f_2 + F_H \times f_3 \]  
\[ E_m = E_U \times f_1 + E_S \times f_2 + E_H \times f_3 \]  

\( F_C \) - fuel consumption, \( F_U \) - urban fuel consumption, \( F_S \) - suburb fuel consumption, \( F_H \) - highway fuel consumption, \( E_m \) - urban emission, \( E_S \) - suburb emission, \( E_H \) - highway emission

\( f_1 \) - urban mileage distribution coefficient, \( f_2 \) - suburb mileage distribution coefficient, \( f_3 \) - highway mileage distribution coefficient

4. Results

4.1. Working condition comparison

Figure 4 and 5 are the vehicle speed and engine speed relationship diagram, they are the gears distribution of the vehicle. From the comparison of these two pictures, we can see that the PEMS test is more closer to the actual road uses of vehicle, while the chassis dynamometer test is not. Its more like a programmed operating condition. Figure 5 show that the gear shift engine speed did not exceed 1800r/min, for the C-WTVC cycle had many acceleration condition and the vehicle must always follow the speed requirements of the curve. It is required in the standard that the running state of the vehicle should be consistent with the cycle as far as possible, and the speed deviation should not exceed \( \pm 3\) km/h. The time of exceeding the speed deviation should not exceed 2S each time, and the accumulated time should not exceed 10s. Thus in the C-WTVC cycle vehicle mostly run in the small and medium engine speed and not exceed 90km/h. While in the PEMS condition vehicle run more engine condition and more actual than that in C-WTVC.

Figure 6 and 7 are the engine torque and speed relationship diagram which echoing the above pictures, the curve in the pictures is the engine performance curve and show that the maximum torque of the engine is 450N.m. These two picture show that the PEMS test common engine working area from 700r/min to 2500r/min, while the C-WTVC are 700r/min to 2100r/min. Mostly it did not reach the maximum torque and the C-WTVC reached. This will explain the fuel consumption in the 4.2 section.
4.2. Fuel consumption and pollutant comparison

For the carbon balance method used to calculate the fuel consumption, the CO2 emission compared in the above pictures as figure 8 and 9, because the CO2 emission occupy mostly of the CO, CO2 and THC emission. Firstly, the above diagrams comparison show that the C-WTVC had more idle speed conditions than that in PEMS test. For the CO2 emission were high in C-WTVC cycle than that in PEMS test under the engine speed 700r/min to 1300r/min. It is also indicated that the engine in this area works mainly in the medium and heavy load area in C-WTVC test. While the PEMS test engine worked in the small load in this area. Most of the CO2 emission in PEMS test were higher than that in C-WTVC cycle, especially the engine speed from 1300r/min to 1900r/min. Obviously we can see that the whole CO2 emission are more higher in PEMS test than that in C-WTVC test.
The NOx emission figure comparison are figure 10 and 11, they show that the PEMS test NOx emission were high than that of C-WTVC test. As we can see from figure 6 and 7 the engine working area were mostly different from each other, for the PEMS condition almost occupied most of the engine working area below the engine performance curve, for instance from 1300r/min to 2500r/min at the medium load. Though in the C-WTVC cycle the engine mostly worked below the engine speed 1900r/min at medium and high load. Thus the NOx emission from 1600r/min to 2500r/min were more higher, the average emission were from 0.002g/s to 0.004g/s, which were 4 to 8 times of the C-WTVC cycle. While the biggest NOx emission in these two condition were 0.015g/s and 0.0027g/s. And the high NOx emission working speed usally beyond 1900r/min. As like the NOx emission comparison, the PN emissions distribution trend were similar to the NOx tendency, which can be seen from Figure 12 and 13. It shows that the PN emission in PEMS test were higher than that in C-WTVC test. The highest PN emission was close to 5.50E+09#/s in the working area from 1600r/min to 2500r/min on PEMS condition. While the highest PN emission in C-WTVC cycle was not exceeding 3.00E+09#/s.

From the NOx and PN emission generation mechanism opinion, it can be seen that the PEMS test condition is more fierce than that of C-WTVC cycle condition for the engine working area are more broader and the engine load are more heavier. As we know the PN emission decreases first and then increases with the increase of engine load, the higher peak combustion pressure and oxygen enrichment of the diesel engine are conducive to NOx generation at high loads.
4.3. Results comparison

| Test type | Fuel consumption L/100km | Brake specific emission | Emissions factor |
|-----------|--------------------------|-------------------------|------------------|
|           |                          | NOx emission mg/kW.h | CO emission mg/kW.h | CO2 emission mg/kW.h | PN emission #/kW.h | NOx emission mg/km | CO emission mg/km | CO2 emission mg/km | PN emission #/km |
| PEMS      | 12.54                    | 47                      | 363               | 904590             | 1.76E+11             | 14                 | 153               | 335083             | 6.54E+10          |
| C-WTVC    | 11.38                    | 4                       | 76                | 718280             | 1.08E+11             | 4                  | 31                | 311874             | 6.08E+10          |

Table 3. Test condition proportion

| Test type | Condition proportion |
|-----------|----------------------|
|           | Urban                | Suburban | Highway |
| PEMS      | 44.3%                | 23.0%    | 32.7%   |
| C-WTVC    | 40.0%                | 40.0%    | 20.0%   |

As above table 2 show that the PEMS test fuel consumption and pollutants are larger than C-WTVC. In terms of fuel consumption, the PEMS test is 9.3% higher than C-WTVC. For the brake specific emission, the NOx emission is 91.0% higher than C-WTVC, for which the CO, CO2 and PN emission are 78.9%, 20.6%, 38.7% higher respectively. As for the emissions factor comparison, the NOx, CO, CO2 and PN emission are 69.6%, 79.9%, 6.9% and 7.1% higher than that of C-WTVC test. Obviously we can see that in these two comparison tests, whether fuel consumption or pollutant emissions, the practical road PEMS test results are larger than that of C-WTVC cycles test results on chassis dynamometer.

Table 3 show that the two test methods for this vehicle have different condition proportions, the urban working conditions of the two methods have a small difference, while the suburban working conditions and high-speed working conditions have a large difference. Among them, the suburban working conditions of the C-WTVC cycle have a large proportion, and the corresponding high-speed working conditions have a reduced proportion. This is also the main reason why the engine working area of C-WTVC cycle is smaller, most of the vehicle operating conditions at medium and low speeds, but less at high vehicle speeds.

5. Conclusion

1. The proportion of urban, suburban and highway are 44.3%, 23.0% and 32.7% in the PEMS test, while the corresponding proportion in C-WTVC are 40.0%, 40.0% and 20.0%. The C-WTVC cycle have a large proportion with suburban condition and a reduced high-speed condition.

2. The engine work conditions in PEMS test occupy most of the engine working area under the engine performance curve, mostly from 1300r/min to 2500r/min at the medium load. In the C-WTVC cycle the engine mostly worked below the engine speed 1900r/min at medium and heavy load.

3. Comparing to the C-WTVC test, the fuel consumption is 9.3% higher in PEMS test, the brake specific emission of NOx, PN, CO, CO2 are 91.0%, 38.7%, 78.9% and 20.6% higher respectively on practical road test.

4. The PEMS test is more practical and convenient for vehicle emission test, which has a poor measurement repeatability under the influence of different road conditions. While the C-WTVC test cycle has a good measurement repeatability for its fixed condition, but its fuel consumption and emissions are smaller and not practical.

5. Two kinds of heavy-duty vehicle test methods have their own advantages and disadvantages, next stage we will study the repeatability coefficient of two methods.
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