Influence of Test Methods on Fuel Consumption of Heavy Trucks in China — From C-WTVC to CHTC

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Abstract. In order to reduce vehicle carbon emissions, the Chinese government is drafting new fuel consumption limits standard for heavy commercial vehicles. The standard will adopt new test method, which will have an impact on the results of vehicle fuel consumption. This paper compares the differences between C-WTVC and CHTC, and theoretically evaluates the impact of vehicle fuel consumption. In addition, the impact is empirically analyzed through the actual vehicle test. It is found that the heavy truck switching from C-WTVC to CHTC-HT will increase the fuel consumption by 0.2%-7.6%, and there is a positive correlation between vehicle fuel consumption and gross vehicle weight (GVW). Among them, the increase of fuel consumption is more obvious in the low speed and high speed parts of the test cycle. In order to achieve fuel consumption compliance, enterprises need to focus on low-speed and high-speed fuel consumption performance.

Keywords: Heavy Truck, C-WTVC, CHTC-HT, Fuel consumption.

1. Introduction
Road traffic is one of the main sources of carbon emissions that cause climate change[1]. In 2018, the transportation sector, which includes cars and trucks, aircraft and vessels, accounted for 10% of China's total emissions[2], 71.7% of transport emissions were due to road transport [3]. In order to effectively address climate change, it is necessary to continuously reduce motor vehicle carbon emissions. In 2018, the ownership of vehicles in China exceeded 240 million, of which 78.8% were private passenger vehicles, and less than 20% of commercial vehicles contribute more than 50% of CO2 emissions [4]. Due to the long driving distance and high fuel consumption per vehicle, heavy trucks account for an important proportion of CO2 emissions from commercial vehicles, which is also the focus of management in various countries. The Chinese government has been phasing out high emission vehicles by implementing the Fuel consumption limits for heavy-duty commercial vehicles (GB 30510). Vehicles that do not meet the limit requirements are not allowed to be produced. When testing the fuel consumption of vehicle, the test method and cycle condition have great influence.

In 2011, the Chinese government issued the national standard Fuel consumption test methods for heavy-duty commercial vehicles (GB/T 27840), which stipulates that the fuel consumption of vehicles should be tested according to the China World Transient Vehicle Cycle (C-WTVC). The C-WTVC is adjusted and modified according to the World Transient Vehicle Cycle (WTVC) of the European Union, which is different from the actual driving conditions in China. Therefore, in 2019, China issued the
national standard of China automotive test cycle, and decided to implement the fuel consumption limit of commercial vehicles in the next stage. Heavy-duty commercial vehicles mainly adopt the second part standard of China's driving conditions, that is China automotive test cycle—Part 2: Heavy-duty commercial vehicles (GB/T 38146.2). Therefore, scientific evaluation of the impact of test method adjustment on vehicle fuel consumption has an important impact on the next stage of fuel consumption formulation and vehicle development.

2. Comparison and influence of C-WTVC and CHTC-HT characteristics

2.1. C-WTVC description

C-WTVC is based on WTVC, but the acceleration and deceleration are adjusted to match China’s actual road conditions. Urban, rural, and highway phases were considered during the test [5]. Figure 1 shows the speed and acceleration / deceleration of C-WTVC per second. In urban and rural phases, the vehicle speed is low but the acceleration/deceleration fluctuation is obvious. As to highway phase, the vehicle speed is high but the acceleration and deceleration is little.

![Figure 1. The variation of speed and acceleration / deceleration per second of C-WTVC.](image)

In order to objectively compare the differences between C-WTVC and CHTC-HT, the calculation methods of acceleration/deceleration and the definitions of acceleration, deceleration and idle are consistent. According to the terms and definitions specified in GB / T 38146.2[6], the characteristic parameters of C-WTVC are calculated as follows:

The acceleration/deceleration \( a \) is:

\[
a = \begin{cases} 
0, & i = 1 \\
\frac{v_{i+1} - v_{i-1}}{2} / 3.6, & i = 2, 3, \ldots, T - 1 \\
0, & i = T 
\end{cases}
\]  

(1)

Where, \( i \) is the time, \( v_i \) is the vehicle speed at \( i \) time, and T is the total time.

The mileage \( x \) is:
\[ x = \int_0^T v_t dt \] (2)

The average speed is:

\[ v_{ave} = \frac{x}{T} \] (3)

The average running speed is:

\[ v_{e,ave} = \frac{x}{(T - T_i)} \] (4)

Where, \( T_i \) is the idle time.

Table 1 summarizes the main features of C-WTVC, including time, speed and acceleration, etc. Acceleration means that the acceleration is greater than or equal to 0.15m/s\(^2\). Deceleration means that the acceleration/deceleration is less than -0.15m/s\(^2\). Cruise speed means that the absolute value of acceleration/deceleration is less than 0.15m/s\(^2\) and the driving speed is greater than or equal to 0.5km/h. Idle speed means that the absolute value of acceleration is less than 0.15m/s\(^2\) and the driving speed is less than 0.5km/h.

A C-WTVC runs for 1800 seconds, including 900 seconds in the urban phase, 468 seconds in the rural phase and 432 seconds in the highway phase. The average speed in urban is the lowest, only 22.9km/h, but the idle speed ratio is relatively high, reaching 15.8%. As to highway area, both the maximum speed and the average speed are the highest, and the driving stage is dominated by cruise speed, accounting for 80.5%.

### Table 1. C-WTVC characteristic parameters.

| Features                        | Urban | Rural | Highway | Total |
|---------------------------------|-------|-------|---------|-------|
| Time(s)                         | 900   | 468   | 432     | 1800  |
| Running mileage(km)             | 5.73  | 5.687 | 9.093   | 20.51 |
| Maximum speed(km/h)             | 66.2  | 73.5  | 87.8    | 87.8  |
| Maximum acceleration(m/s\(^2\))| 0.87  | 0.75  | 0.29    | 0.87  |
| Maximum deceleration(m/s\(^2\))| -1.00 | -1.00 | -0.97   | -1.00 |
| Average speed(km/h)             | 22.90 | 43.75 | 75.77   | 41.02 |
| Average running speed (km/h)    | 27.21 | 46.74 | 76.84   | 45.52 |
| Average acceleration in acceleration section(m/s\(^2\)) | 0.39 | 0.32 | 0.21 | 0.36 |
| Average deceleration in deceleration section(m/s\(^2\)) | -0.55 | -0.38 | -0.46 | -0.49 |
| Acceleration ratio (%)          | 35.1  | 39.5  | 3.5     | 28.7  |
| Deceleration ratio (%)          | 25.9  | 24.6  | 14.6    | 22.8  |
| Cruise speed ratio (%)          | 23.2  | 29.5  | 80.5    | 38.6  |
| Idle speed ratio (%)            | 15.8  | 6.4   | 1.4     | 9.9   |

Figure 2 analyzes the relationship between vehicle speed and acceleration in urban, rural and highway phase of C-WTVC. The results show that the highest speed of urban area is only 66.2km/h, but the acceleration/deceleration fluctuation range of speed per second is the widest. The speed of road and highway areas is relatively concentrated, and the distribution of acceleration and deceleration is circular, and more fluctuates at the same level.
2.2. **CHTC description**

The CHTC is defined by national standard GB/T38146.2, China Automotive Test Cycle Part 2: Heavy-duty Commercial Vehicles, released in October 2019 and applicable from May 2020. The CHTC includes six chassis dynamometer driving cycles for various types of heavy commercial vehicles with GVW>3500 kg: CHTC-B (for city buses), CHTC-C (for inter-city coaches), CHTC-LT (for light trucks of GVW≤5500 kg), CHTC-HT (for heavy trucks of GVW>5500 kg), CHTC-D (for dump trucks) and CHTC-TT (for tractor trailers).

This article mainly studies the influence of test cycle change of heavy truck. China heavy-duty commercial vehicle test cycle trunk (GVW > 5500 kg) (CHTC-HT) consists of 3 speed phases: urban phase (phase 1), rural (phase 2) and high speed phase (phase 3) with a total duration of 1800s. Figure 3 shows the overall situation of CHTC-HT, including vehicle speed and acceleration / deceleration per second. In urban and highway conditions, the vehicle speed is not high, but the acceleration and deceleration changes greatly.

Table 2 summarizes the main features of CHTC-HT, including time, speed and acceleration, etc. A CHTC-HT runs for 1800 seconds, including 988 seconds in the rural (phase 2), 342 seconds in urban phase (phase 1) and 470 seconds in high speed phase (phase 3). The average speed in phase 1 is the lowest, only 8.9 km/h, but the idle speed ratio is relatively high, reaching 42.4%. For high speed phase, both the maximum speed and the average speed are the highest, and the driving stage is dominated by cruise speed, accounting for 52.77%.
Figure 3. The variation of speed and acceleration / deceleration per second of CHTC-HT.

Table 2. CHTC-HT characteristic parameters.

| Features                              | Phase 1 | Phase 2 | Phase 3 | Total   |
|---------------------------------------|---------|---------|---------|---------|
| Time (s)                              | 342     | 988     | 470     | 1800    |
| Running mileage (km)                   | 0.49    | 8.59    | 8.25    | 17.33   |
| Maximum speed (km/h)                  | 21.4    | 64      | 88.5    | 88.5    |
| Maximum acceleration (m/s²)           | 0.89    | 1.14    | 0.85    | 1.14    |
| Maximum deceleration (m/s²)           | -1.04   | -1.21   | -1.1    | -1.21   |
| Average speed (km/h)                  | 5.13    | 31.28   | 63.22   | 34.65   |
| Average running speed (km/h)          | 8.9     | 34.04   | 66.92   | 40.16   |
| Average acceleration in acceleration section (m/s²) | 0.32    | 0.31    | 0.31    | 0.31    |
| Average deceleration in deceleration section (m/s²) | -0.34   | -0.49   | -0.44   | -0.45   |
| Acceleration ratio (%)                | 13.16   | 27.94   | 23.62   | 24.22   |
| Deceleration ratio (%)                | 13.45   | 19.64   | 18.09   | 18.06   |
| Cruise speed ratio (%)                | 30.99   | 44.33   | 52.77   | 44      |
| Idle speed ratio (%)                  | 42.4    | 8.1     | 5.53    | 13.72   |

Figure 4 analyzes the relationship between speed and acceleration in urban, rural and high-speed phase of CHTC-HT. Different from C-WTVC, the maximum speed of CHTC-HT in different phases is significantly different. It can reach 88.5km/h in high-speed phase and only 21.4km/h in urban phase. While there is no significant difference in acceleration and deceleration.
2.3. Comparison of two cycles

2.3.1. Comparison of overall indicators. Figure 5 shows the difference of CHTC-HT and C-WTVC. The speed of CHTC-HT is lower than that of C-WTVC most of the time, but the speed change is more dramatic at each time point. Especially in the high-speed phase, the C-WTVC is relatively uniform, while the CHTC-HT has obvious acceleration and deceleration changes. This will increase the energy demand of the vehicle.

The characteristics of CHTC-HT and C-WTVC are compared in Table 2. Compared with C-WTVC, if the result of one indicator of CHTC-HT is better, it is indicated by “√”; if the result of one indicator is worse, it is indicated by “×”; if it is the same, it is indicated by “-”.

The difference between the maximum speed of CHTC-HT and C-WTVC is little, but the average speed of CHTC is lower. The acceleration and deceleration of CHTC is more intense than C-WTVC. In addition, there is a significant difference between CHTC-HT and C-WTVC in driving stage, and the idle ratio of CHTC is higher. To sum up, it can be seen that the increasing demand for vehicle power under CHTC-HT will lead to the increase of vehicle fuel consumption.
Table 3. Comparison of key indicator of CHTC-HT and C-WTVC.

| Features                              | CHTC-HT | C-WTVC | The level of CHTC-HT |
|---------------------------------------|---------|--------|---------------------|
| Time (s)                              | 1800    | 1800   | -                   |
| Running mileage (km)                  | 17.33   | 20.51  | ×                   |
| Maximum speed (km/h)                 | 88.5    | 87.8   | -                   |
| Maximum acceleration (m/s²)          | 1.14    | 0.87   | √                   |
| Maximum deceleration (m/s²)          | -1.21   | -1.00  | √                   |
| Average speed (km/h)                 | 34.65   | 41.02  | ×                   |
| Average running speed (km/h)         | 40.16   | 45.52  | ×                   |
| Average acceleration in acceleration section (m/s²) | 0.31    | 0.36   | ×                   |
| Average deceleration in deceleration section (m/s²) | -0.45   | -0.49  | ×                   |
| Acceleration ratio (%)               | 24.22   | 28.7   | ×                   |
| Deceleration ratio (%)               | 18.06   | 22.8   | ×                   |
| Cruise speed ratio (%)               | 44      | 38.6   | ×                   |
| Idle speed ratio (%)                 | 13.72   | 9.9    | √                   |

2.3.2. Acceleration comparison. Figure 6 compares the acceleration/deceleration points corresponding to different speeds under CHTC-HT and C-WTVC conditions. It can be seen that at the same speed point, the fluctuation range of C-WTVC acceleration/deceleration is significantly lower than that of CHTC-HT. It shows that the acceleration/deceleration behavior corresponding to CHTC is more frequent, which leads to higher vehicle energy demand. Higher vehicle energy demand directly leads to the increase of vehicle fuel consumption.

![Figure 6. Velocity acceleration/deceleration comparison between CHTC-HT and C-WTVC.](image)

2.3.3. Mileage distribution difference. C-WTVC consist of urban, rural and high-speed phase. When calculating the fuel consumption of vehicles, it is weighted according to the fuel consumption of the three phases. For different GVW models, the allocation proportion of the three phase is different. CHTC is also divided into three phase: urban, rural and high-speed, which can be calculated according to the method specified in GB / T 27840.

Figure 7 shows the comparison of the three phase under C-WTVC and CHTC. The urban, rural and high-speed phase of CHTC-HT respectively correspond to the C-WTVC, which is divided into urban, rural and highway. It can be seen that, compared with C-WTVC, the proportion of CHTC-HT in urban phase is lower than C-WTVC, and the time proportion of high-speed phase is lower than C-WTVC. Due
to the high fuel consumption at low speed and low fuel consumption at high speed, the change of mileage distribution mode further leads to the increase of fuel consumption caused by cycle switching. As the mileage proportion of heavier vehicles in high-speed section changes most obviously, it is expected that the fuel consumption of vehicles will increase, and the impact on heavier vehicles will be more obvious.

Notes: 1 for $5500 < \text{GVW} \leq 12500\text{kg}$; 2 for $12500 < \text{GVW} \leq 25000\text{kg}$; 3 for $25000\text{kg} < \text{GVW}$.

Figure 7. Proportion allocation of different driving phases on CHTC-HT and C-WTVC.

3. Influence of CHTC-HT on fuel consumption of vehicles

3.1. Test vehicle

6 representative heavy-duty trucks in the market were selected to test the fuel consumption according to CHTC-HT and C-WTVC. The vehicles’ parameters are shown in Table 4. It can be seen that the vehicles come from four companies: China first automobile group co., LTD.(FAW), Shaanxi Automobile Group Co., Ltd. (SAGC), Dongfeng Liuzhou Motor Co., Ltd. (DFLZM) and Jianghuai Auto Group Co., Ltd. (JAC). The vehicle GVW range from 7.36 to 31 tons.

Table 4. Comparison of key indicators of CHTC-HT and C-WTVC.

| Items  | Vehicle 1 | Vehicle 2 | Vehicle 3 | Vehicle 4 | Vehicle 5 | Vehicle 6 |
|--------|-----------|-----------|-----------|-----------|-----------|-----------|
| Company| -         | FAW       | FAW       | JAC       | DFLZM     | SAGC      |
| GVW(kg)| 7360      | 17500     | 17500     | 18000     | 31000     | 31000     |

3.2. Result analysis

During the test, the road resistance is simulated by the dynamometer, and the fuel consumption is measured by the fuel consumption meter. The fuel consumption results of the test vehicle under CHTC-HT and C-WTVC are shown in Figure 8. In the figure, the weighted fuel consumption of different driving phases is considered, and the fuel consumption results of the model are reflected in strict accordance with the requirements of the new standard.

The vehicle fuel consumption in the urban phase and high-speed phase of CHTC-HT is higher than that of C-WTVC, and the fuel consumption of urban phase increases significantly, up to 46%. At rural phase, the fuel consumption of CHTC-HT is lower than that of C-WTVC.
Figure 8. Fuel consumption test results of CHTC-HT and C-WTVC at different phases.

Figure 9 shows the changes of vehicle fuel consumption under CHTC-HT and C-WTVC conditions. Considering the fuel consumption of different types of vehicles with different driving weights, it is found that the fuel consumption of all vehicles increases after switching from C-WTVC to CHTC-HT, ranging from 0.2% to 7.6%. There is a positive correlation between vehicle fuel consumption and gross vehicle weight (GVW). With the increase of GVW, the growth of vehicle fuel consumption has an upward trend.

Figure 9. Fuel consumption test results of CHTC-HT and C-WTVC.

4. Conclusions

Heavy commercial vehicles are the main source of carbon emissions in the transportation sector. In order to reduce vehicle carbon emissions, the Chinese government is drafting new fuel consumption limits standard for heavy commercial vehicles, and the standard will adopt new test method, which will have an impact on the results of vehicle fuel consumption.

This report compares the differences between C-WTVC and CHTC, and theoretically evaluates the impact of vehicle fuel consumption. In addition, the impact is empirically analyzed through the actual vehicle test. It is found that:

1. Compared with C-WTVC, CHTC-HT has the characteristics of more idle speed, lower running speed and more frequent acceleration and deceleration, which will lead to the increase of vehicle energy demand and fuel consumption.
(2) According to the actual test results of the vehicles, the heavy-duty truck test cycle switching from C-WTVC to CHTC-HT will increase the fuel consumption by 0.2%-7.6%, and there is a positive correlation between vehicle fuel consumption and gross vehicle weight (GVW).

(3) The increase of fuel consumption is more significant in the urban and high-speed phases of the cycle. In order to achieve fuel consumption compliance, enterprises need to focus on urban and high-speed fuel consumption performance.

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