Fuel consumption comparison of heavy-duty commercial vehicles under CHTC and C-WTVC cycles based on VECTO

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Keywords: Heavy-duty vehicle, C-WTVC, CHTC, Fuel Consumption, VECTO.

Abstract. In this paper, the simulation method of calculating the fuel consumption of heavy-duty commercial vehicles based on VECTO (Vehicle Energy Consumption Calculation Tool) was introduced, and the fuel consumption of four vehicles under C-WTVC and CHTC cycles was calculated with VECTO. The differences between C-WTVC and CHTC cycles were analyzed by comparing the characteristic parameters, and the fuel consumption map and driving acceleration of two cycles were compared, so as to explore the influence of different test cycles on fuel consumption. The results show that compared with the C-WTVC cycle, the fuel consumption of CHTC cycle increases by 17.08g/km~28.12g/km, with an increase of 6.42%~17.26%. Most of the engine working points in the CHTC cycle work in the middle and low speed and torque regions and the acceleration range of CHTC cycle is wider are important reasons for the increase of fuel consumption.

1 Introduction

Although the market share of heavy-duty commercial vehicles is less than that of light-duty vehicles, the fuel consumption and emissions of single vehicle are higher and the proportion of the total fuel consumption and emissions is larger. Therefore, heavy-duty commercial vehicles have always been the key prevention and control object of energy conservation and emission reduction of motor vehicles in China[1]. However, the main way to strengthen the supervision of energy saving and emission reduction of heavy-duty commercial vehicles is to upgrade the fuel consumption and emission regulations. The choice of test cycle will directly affect the setting of the limit values of fuel consumption and emission. The more the test cycle is in line with the road conditions in China, the closer the measured values of the fuel consumption and emission of heavy-duty commercial vehicles will be to the reality, the more effective the regulation of the fuel consumption and

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emission regulations on energy saving and emission reduction of heavy-duty commercial vehicles is[2].

At present, the C-WTVC cycle is used for the fuel consumption and emission test of heavy-duty commercial vehicles in China, which is based on the World Transient Vehicle Cycle (WTVC), adjusting acceleration and deceleration. The GB/T 38146.2-2019 "China automotive test cycle -Part 2: Heavy-duty commercial vehicles" includes The China heavy-duty commercial vehicle test cycle (CHTC), that may be applied to fuel consumption and emission regulations in the future[3].

In addition, because there are many variants of heavy-duty commercial vehicles, the cost of chassis dynamometer test for all variants is high, and the engine dynamometer test can not get the test results of the whole vehicle. Therefore, the GB / T 27840-2011 "Fuel consumption test method for heavy-duty commercial vehicles" requires that the chassis dynamometer method be used to measure the fuel consumption for basic vehicles, and the simulation calculation method can be used for variant vehicles[4]. Software simulation calculation method is also widely used in developed countries , such as the GEM (Greenhouse Gas Emission Model) in the United States and the VECTO (Vehicle Energy Consumption Calculation Tool) in the European Union[5-9].

In this paper, the CHTC and C-WTVC cycles are compared, the fuel consumption of different types of heavy-duty commercial vehicles under two test cycles is simulated by VECTO, and then the simulation process and results are analyzed. The influence of the test cycle on the measurement results of fuel consumption is explored.

2 Simulation calculation method of fuel consumption based on VECTO

VECTO calculates the fuel consumption of heavy-duty commercial vehicles by combining the component test and vehicle simulation, as shown in Figure 1. The test data of components can be applied to different variants of vehicles, and the vehicle simulation can effectively eliminate the influence of driver behavior and environmental conditions on the test results. This method not only saves the test cost, but also has good repeatability and flexibility.

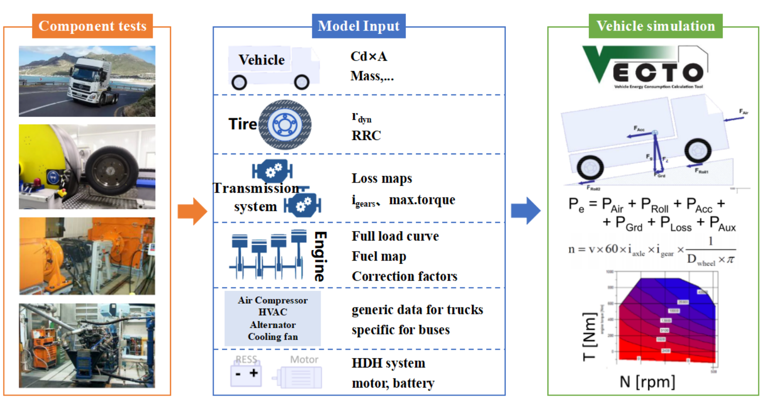


Fig. 1. Principle and method of the VECTO calculation.

The component test mainly includes engine test, transmission system test, gearbox test, reducer test, air drag test and tire test. The test data needs to be processed into the corresponding format data file before it can be input into VECTO software for the calculation of fuel consumption, as shown in Figure 2. Among them, the test data of engine and air drag need to go through a separate calculation tool to obtain the parameters needed for the calculation of fuel consumption[10].

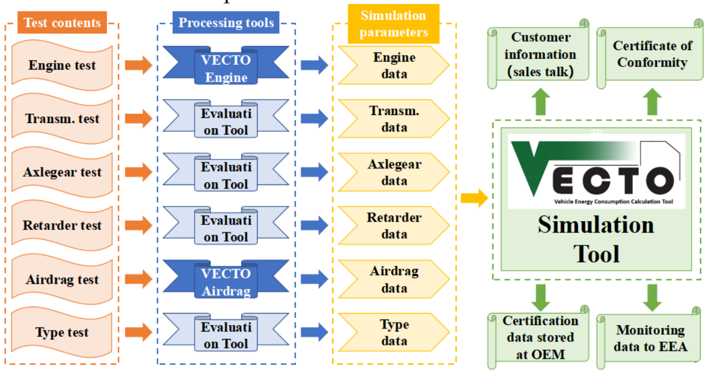


Fig. 2. Data processing of the VECTO calculation.

2.1 VECTO engine

VECTO Engine is a tool to check the engine test data and calculate the parameters needed for vehicle simulation. Firstly, the working conditions of the test points in the fuel consumption map of the parent engine are calculated by inputting the engine idle speed and full load curve of the parent engine, as shown in Figures 3 and 4.

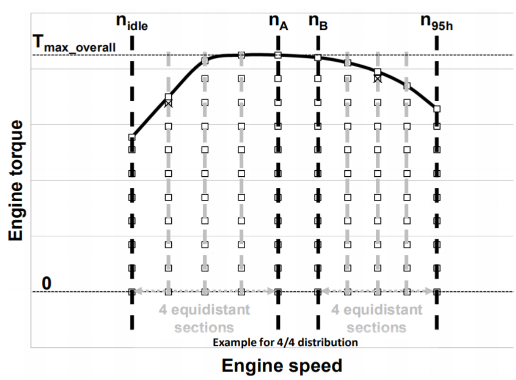


Fig. 3. Vertical split points of fuel consumption map.

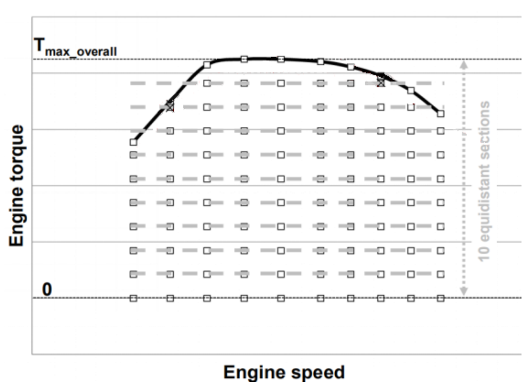


Fig. 4. Horizontal split points of fuel consumption map.

Then the fuel consumption of the test points is measured in the order shown in Figure 5 to obtain the fuel consumption map of the parent engine. Finally, the parameters and files in Table 1 are input into VECTO Engine to calculate the WHTC correction factors.

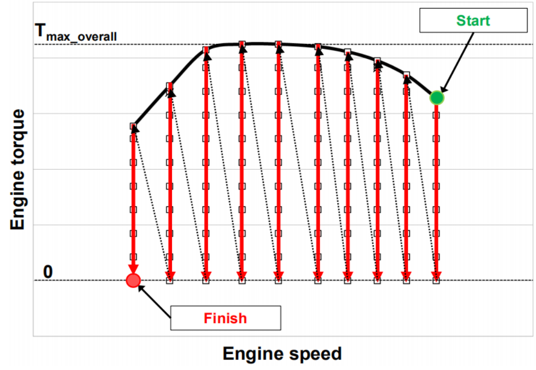


Fig. 5. Measured order of the engine test points.

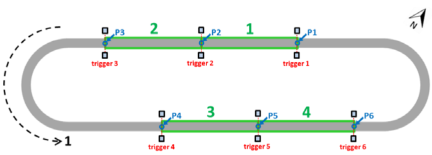
Table 1. The required parameters/files of VECTO Engine.

Number	Parameter/File	Unit/Format
1	Idle speed of parent engine	1/min
2	Engine idle speed	1/min
3	Engine displacement	ccm
4	Engine rated power	kW
5	Engine rated speed	1/min
6	Type of test fuel	
7	NCV of test fuel	MJ/kg
8	Fuel consumption map of parent engine	.csv
9	Full load curve of parent engine	.csv
10	Full load curve	.csv
11	Motoring curve of parent engine	.csv
12	WHTC coldstart total	g/kWh
13	WHTC hotstart total	g/kWh
14	WHTC-Urban	g/kWh
15	WHTC-Rural	g/kWh
16	WHTC-Motorway	g/kWh
17	CF-RegPer	

2.2 VECTO airdrag

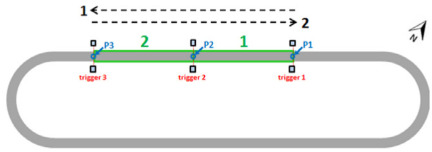
VECTO Airdrag is a tool to calculate the air drag of the whole vehicle through misalignment test and constant speed test. There are two kinds of test tracks, as shown in Figure 6.

Constant speed test includes the low speed test of 15 km/h and the high speed test of 90 km/h. Misalignment test is carried out at the high speed of 90 km/h. During the constant speed test, actual air velocity and direction, wheel torque of driven wheel, engine speed, vehicle velocity and vehicle position need to be measured. The required equipment is shown in Figure 7.



meas. section ID #[id]	direction ID [id]	lenght [m]	heading [°]	latitude start [mm.mm]	longitude start [mm.mm]	latitude end [mm.mm]	longitude end [mm.mm]
1	1	250	236	..P1..	..P1..	..P2..	..P2..
2	1	250	236	..P2..	..P2..	..P3..	..P3..
3	1	250	56	..P4..	..P4..	..P5..	..P5..
4	1	250	56	..P5..	..P5..	..P6..	..P6..

(a) Cycle test track



meas. section ID #[id]	direction ID [id]	lenght [m]	heading [°]	latitude start (D) [dd.dd]	longitude start (D) [dd.dd]	latitude start (D) [dd.dd]	longitude start (D) [dd.dd]
1	1	250	236	..P1..	..P1..	..P2..	..P2..
2	1	250	236	..P2..	..P2..	..P3..	..P3..
2	2	250	56	..P3..	..P3..	..P2..	..P2..
1	2	250	56	..P2..	..P2..	..P1..	..P1..

(b) Round trip test track

Fig. 6. Test tracks of the VECTO airdrag.

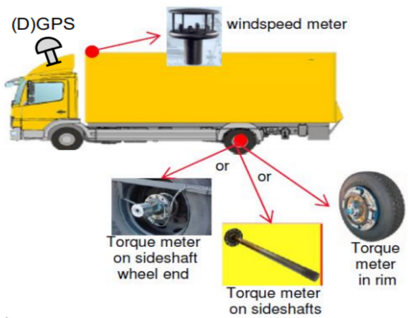


Fig. 7. The required equipment of constant speed test.

All test data are input into the Additional MS Excel tool for inspection, and the data files needed to calculate the vehicle air drag are generated, which will be input into the VECTO Airdrag together with the vehicle and environmental data files, in order to calculate the value of Cd·A. All the data files required by the VECTO Airdrag are shown in Table 2.

Table 2. The required files of VECTO Airdrag.

Number	File	Format
1	Vehicle file	.csveh, json
2	Misalignment data file	.osdat
3	Measurement section configuration file of misalignment test	.csms
4	Ambient conditions file	.csamb
5	Measurement section configuration file of constant speed test	.csms
6	Low-speed 1 data file	.csdat
7	High-speed data file	.csdat
8	Low-speed 2 data file	.csdat

2.3 VECTO simulation tool

VECTO Simulation Tool is a tool to calculate fuel consumption with component parameters, mainly including vehicle, engine, gearbox, job file and other modules. When calculating the fuel consumption, it is necessary to input the vehicle, engine and gearbox parameters into corresponding module to get the data files in the required format. Then, the above data files and test cycles files are input into the job file module to get the data file for fuel consumption calculation. After calculation, the files of transient and final fuel consumption results under test cycles are obtained. The operation flow of VECTO Simulation Tool is shown in Figure 8, and the required data files are shown in Table 3.

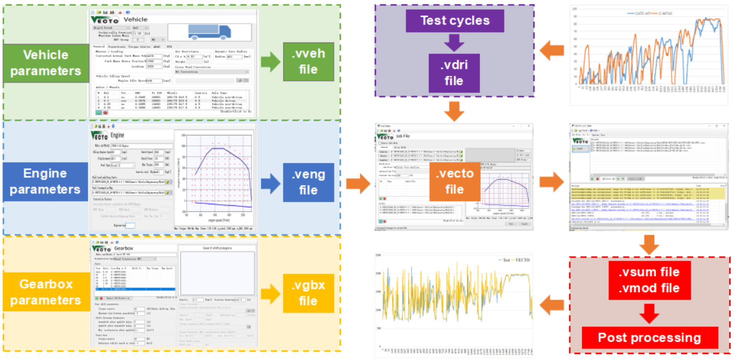


Fig. 8. The operation flow of VECTO Simulation Tool.

Table 3. The required files of VECTO Airdrag.

Number	File	Format
1	Vehicle parameters	.vveh
2	Engine parameters	.veng
3	Gearbox parameters	.vgbx
4	Test cycle	.vdri
5	Job file	.vecto
6	transient fuel consumption results	.vmod
7	final fuel consumption results	.vsum

3 Simulation setup for calculating fuel consumption

3.1 Main parameters of the vehicles

Four types of heavy-duty commercial vehicles are selected for component test, and the fuel consumption of the whole vehicle is simulated by VECTO. The main parameters of the vehicles are shown in Table 4.

Table 4. The main parameters of the vehicles.

Parameter	Vehicle one	Vehicle two	Vehicle three	Vehicle four
Type	Bus	Coach	Truck	Tractor-trailer
Total mass	11990kg	25000kg	10000kg	18000kg
Curb mass	4670kg	14800kg	4320kg	8230kg
Engine idle speed	600rpm	600rpm	600rpm	600rpm
Engine rated speed	2200rpm	1740rpm	2200rpm	1740rpm
Engine rated power	175kw	250kw	150kw	325kw
Engine displacement	6871ccm	7700ccm	5670ccm	12740ccm

3.2 Simulation tools

In this paper, the VECTO Engine is used to process the engine test data, the value of Cd× A, which represents the air drag, is obtained through the VECTO Airdrag. Finally, the calculation of fuel consumption is completed in the VECTO Simulation Tool. The information of the simulation tools are shown in Table 5.

Table 5. The information of the simulation tools.

Simulation tool	Edition
VECTO Engine	1.4.4.1492
VECTO Airdrag	3.1.9
VECTO Simulation Tool	3.3.9.2175

3.3 Test cycles

In this part, the characteristics of C-WTVC and CHTC cycles are introduced respectively, and their characteristic parameters are compared. On this basis, the possible influence of test cycle on vehicle fuel consumption is analyzed.

3.3.1 C-WTVC cycle

C-WTVC cycle adopts a unified test curve, which is composed of urban, rural and motorway, as shown in Figure 9. According to different types of heavy-duty commercial vehicles, the different characteristic mileage distribution proportions in three cycle intervals are determined, as shown in Table 6[4]. The comprehensive fuel consumption of heavy-duty commercial vehicles is calculated by weighting the test results in each cycle interval.

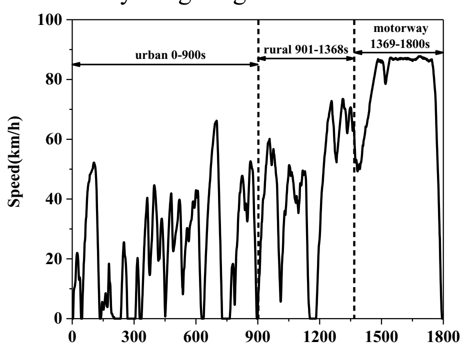


Fig. 9. Test curve of C-WTVC cycle.

Table 6. Classification of heavy-duty commercial vehicles and their characteristic mileage distribution proportions.

Vehicle type	Max design total mass GCW/GVW/kg	D_{urban}	D_{rural}	$D_{motorway}$
Tractor-trailer	9000＜GCW≤27000	0	40%	60%
	GCW＞27000	0	10%	90%
Dumper	GVW＞3500	0	100%	0
Truck	3500＜GVW≤5500	40%	40%	20%
	5500＜GVW≤12500	10%	60%	30%
	12500＜GVW≤25000	10%	40%	50%

	GVW＞25000	10%	30%	60%
Bus	GVW＞3500	100%	0	0
	3500＜GVW≤5500	50%	25%	25%
Coach	5500＜GVW≤12500	20%	30%	50%
	GVW＞12500	10%	20%	70%

3.3.2 CHTC cycle

CHTC cycle consists of six test curves, which are the China heavy-duty commercial vehicle test cycle for bus (CHTC-B), the China heavy-duty commercial vehicle test cycle for coach (CHTC-C), the China heavy-duty commercial vehicle test cycle for truck (GVW⩽5500kg) (CHTC-LT), the China heavy-duty commercial vehicle test cycle for truck (GVW＞5500kg) (CHTC-HT), the China heavy-duty commercial vehicle test cycle for dumper (CHTC-D) and the China heavy-duty commercial vehicle test cycle for tractor-trailer (CHTC-TT)[3]. At this time, the comprehensive fuel consumption of heavy-duty commercial vehicles is directly calculated from the measurement results under the corresponding test curve.

3.3.3 Comparison and analysis of two cycles

This paper calculates the characteristic parameters of C-WTVC cycle based on the definitions of CHTC cycle, so as to compare the differences between the two cycles.
3.3.3.1 Bus
The test curves and characteristic parameters of bus under CHTC-B and C-WTVC cycles are shown in Figure 10 and table 7. Compared with C-WTVC cycle, CHTC-B cycle has longer running time, lower maximum acceleration, average speed and average running speed, higher idle ratio and lower acceleration ratio, which can better reflect the characteristics of low average speed and high idle speed ratio of bus.

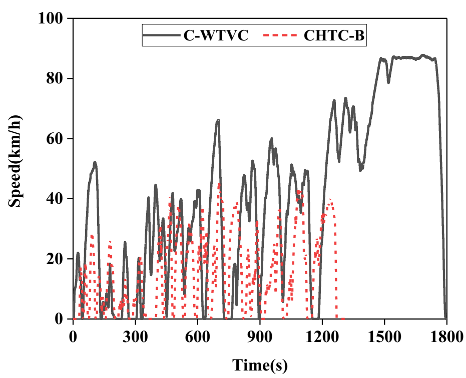


Fig. 10. Test curves of CHTC-B and C-WTVC cycles.

Table 7. The characteristic parameters of bus under CHTC-B and C-WTVC cycles.

Characteristic parameter	CHTC-B cycle	Urban part of C-WTVC cycle
Running time/s	1310	900
Distance/km	5.49	5.73
Max speed/(m/s)	45.60	66.20
Max acceleration/($m \cdot s^{-2}$)	1.26	0.88
Max deceleration/($m \cdot s^{-2}$)	-1.32	-1.00

Average speed/(m/s)	15.08	22.90
Average running speed/(m/s)	19.43	27.21
Average acceleration/(m·s^{-2})	0.48	0.39
Average deceleration/(m·s^{-2})	-0.54	-0.55
Relative positive acceleration/(m·s^{-2})	0.17	0.15
Acceleration ratio/%	29.16	35.18
Deceleration ratio/%	25.88	25.86
Cruise ratio/%	22.60	23.09
Idle ratio/%	22.37	15.87

3.3.3.2 Coach

The test curves and characteristic parameters of coach under CHTC-C and C-WTVC cycles are shown in Figure 11 and table 8. Compared with C-WTVC cycle, CHTC-C cycle has higher idle ratio and lower cruise ratio, deceleration ratio and acceleration ratio.

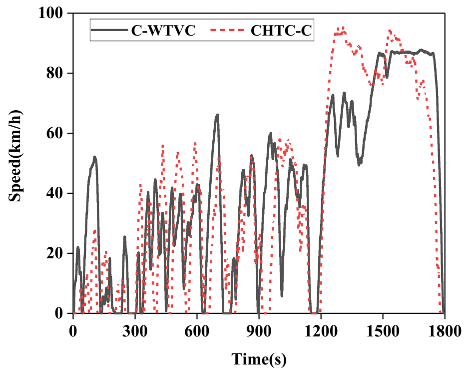


Fig. 11. Test curves of CHTC-C and C-WTVC cycles.

Table 8. The characteristic parameters of coach under CHTC-C and C-WTVC cycles.

Characteristic parameter	CHTC-C cycle	C-WTVC cycle
Running time/s	1800	1800
Distance/km	19.62	20.51
Max speed/(m/s)	95.7	87.8
Max acceleration/(m·s^{-2})	1.25	0.88
Max deceleration/(m·s^{-2})	-0.13	-1.00
Average speed/(m/s)	39.24	41.00
Average running speed/(m/s)	47.98	45.52
Average acceleration/(m·s^{-2})	0.43	0.36
Average deceleration/(m·s^{-2})	-0.48	-0.48
Relative positive acceleration/(m·s^{-2})	0.10	0.09
Acceleration ratio/%	26.22	28.76
Deceleration ratio/%	22.56	22.87
Cruise ratio/%	33.00	38.53
Idle ratio/%	18.22	9.94

3.3.3.4 Truck (GVW＞5500kg)

The test curves and characteristic parameters of truck (GVW＞5500kg) under CHTC-HT and C-WTVC cycles are shown in Figure 5 and table 5. Compared with C-WTVC cycle, CHTC-HT cycle has higher idle ratio and cruise ratio, lower acceleration ratio and deceleration ratio, higher average speed and average running speed, lower maximum acceleration and maximum deceleration.

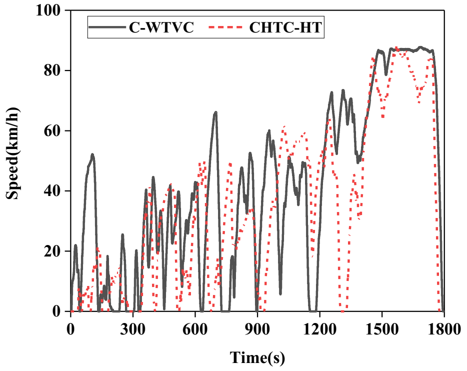


Fig. 12. Test curves of CHTC-HT and C-WTVC cycles.

Table 9. The characteristic parameters of truck (GVW＞5500kg) under CHTC-HT and C-WTVC cycles.

Characteristic parameter	CHTC-HT cycle	C-WTVC cycle
Running time/s	1800	1800
Distance/km	17.33	20.51
Max speed/(m/s)	88.5	87.8
Max acceleration/($m\cdot s^{-2}$)	1.14	0.88
Max deceleration/($m\cdot s^{-2}$)	-1.21	-1.00
Average speed/(m/s)	34.65	41.00
Average running speed/(m/s)	40.16	45.52
Average acceleration/($m\cdot s^{-2}$)	0.31	0.36
Average deceleration/($m\cdot s^{-2}$)	-0.45	-0.48
Relative positive acceleration/($m\cdot s^{-2}$)	0.09	0.09
Acceleration ratio/%	24.22	28.76
Deceleration ratio/%	18.06	22.87
Cruise ratio/%	44.00	38.53
Idle ratio/%	13.72	9.94

3.3.3.6 Tractor-trailer

The test curves and characteristic parameters of tractor-trailer under CHTC-TT and C-WTVC cycles are shown in Figure 13 and table 10. Compared with C-WTVC cycle, CHTC-TT cycle has longer running time and distance, lower average speed, higher idle ratio and cruise ratio.

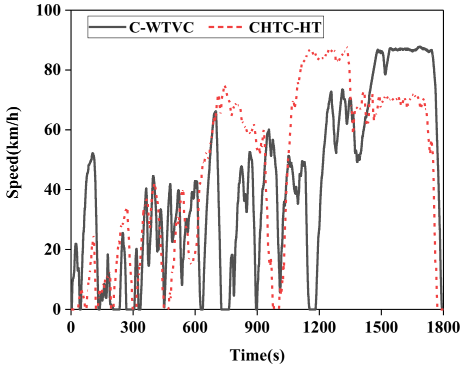


Fig. 13. Test curves of CHTC-TT and C-WTVC cycles.

Table 10. The characteristic parameters of tractor-trailer under CHTC-TT and C-WTVC cycles.

Characteristic parameter	CHTC-TT cycle	Rural and Motorway part of C-WTVC cycle
Running time/s	1800	900
Distance/km	23.22	14.78
Max speed/(m/s)	88.00	87.80
Max acceleration/($m \cdot s^{-2}$)	0.81	0.75
Max deceleration/($m \cdot s^{-2}$)	-1.04	-1.00
Average speed/(m/s)	46.44	59.05
Average running speed/(m/s)	50.82	61.51
Average acceleration/($m \cdot s^{-2}$)	0.28	0.31
Average deceleration/($m \cdot s^{-2}$)	-0.36	-0.40
Relative positive acceleration/($m \cdot s^{-2}$)	0.06	0.07
Acceleration ratio/%	17.44	22.31
Deceleration ratio/%	15.78	19.76
Cruise ratio/%	58.17	53.94
Idle ratio/%	8.61	4.00

It can be seen from the above comparison that, CHTC cycle has higher idle ratio, lower average speed, higher maximum acceleration and deceleration and higher relative positive acceleration compared with C-WTVC cycle.

4 Comparison and analysis of the calculation results

The fuel consumption of the four vehicles under C-WTVC and CHTC cycles is calculated by VECTO, the fuel consumption map and driving acceleration are compared and analyzed to deeply understand the influence of test cycles on fuel consumption.

4.1 Analysis of fuel consumption calculation results

The calculation results of comprehensive fuel consumption of the vehicles under C-WTVC and CHTC cycles are shown in Figure 14. Among the four types of vehicles, the tractor-trailer has the highest fuel consumption, that fuel consumption of the tractor-trailer under C-WTVC cycle and CHTC cycle are 266.15g/km and 283.23g/km respectively, and it also has the lowest increase, that compared with C-WTVC cycle, its fuel consumption under CHTC cycle increases only 6.42%. The lowest fuel consumption of them is the truck, whose fuel consumption under C-WTVC and CHTC cycles are 139.63g/km and 157g/km respectively, but its increase is 12.4%, not the height. The vehicle with the highest increase is the bus, whose increase is 17.26% with the fuel consumption under C-WTVC and CHTC cycles are 162.92g/km and 191.04g/km respectively. And the fuel consumption of the coach under C-WTVC cycle and CHTC cycle are 234.33g/km and 254.47g/km respectively, while its increase is 8.6%. In a word, compared with C-WTVC cycle, the fuel consumption of CHTC cycle increases by 17.08g/km~28.12g/km, with an increase of 6.42%~17.26%. The increment and increase of fuel consumption of bus are the largest, and those of tractor-trailer are the smallest.

https://doi.org/10.1051/e3sconf/202236001009

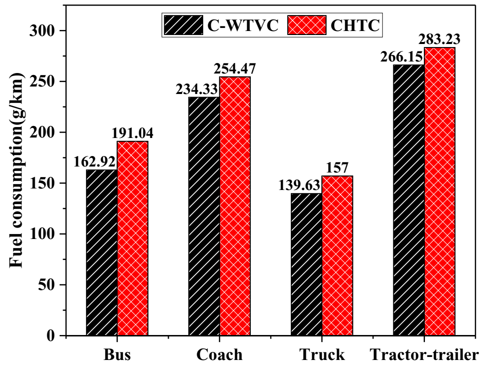
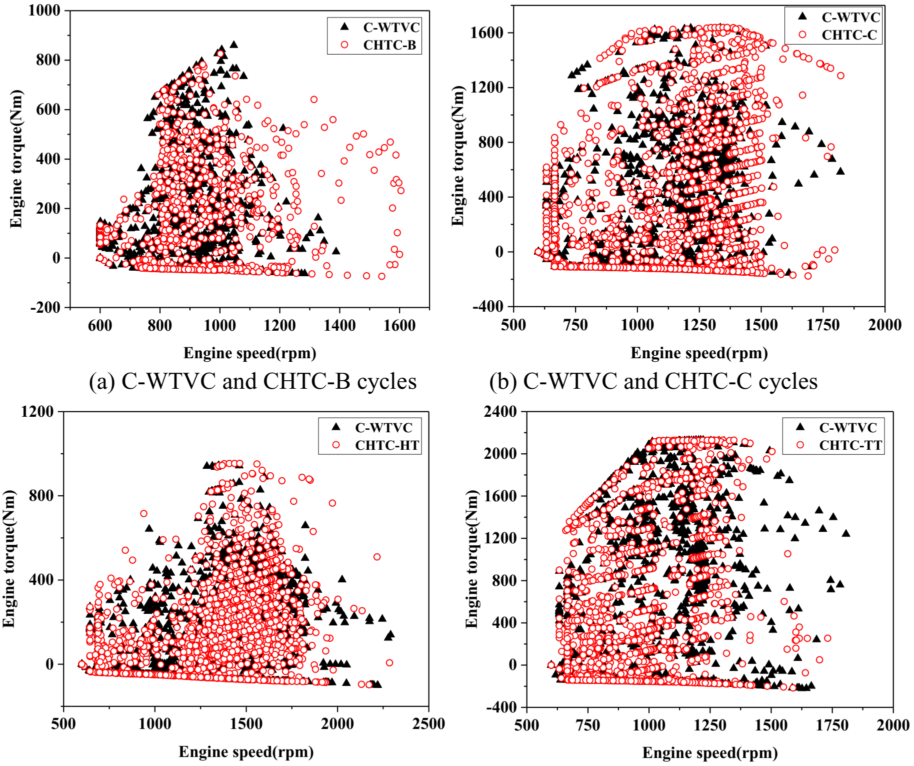


Fig. 14. The comprehensive fuel consumption of the vehicles under C-WTVC and CHTC cycles.

4.2 Analysis of fuel consumption MAP

The fuel consumption maps of the vehicles under C-WTVC and CHTC cycles are shown in Figure 15. It can be seen from the figure that compared with the C-WTVC cycle, most of the engine working points in the CHTC cycle work in the middle and low speed and torque regions, resulting in increased fuel consumption.



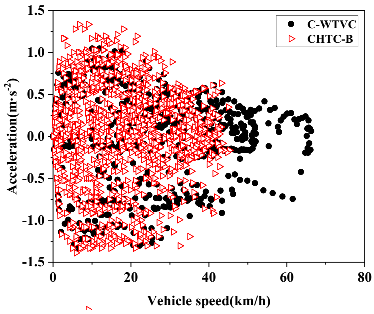
(a) C-WTVC and CHTC-B cycles (b) C-WTVC and CHTC-C cycles

(c) C-WTVC and CHTC-HT cycles (d) C-WTVC and CHTC-TT cycles

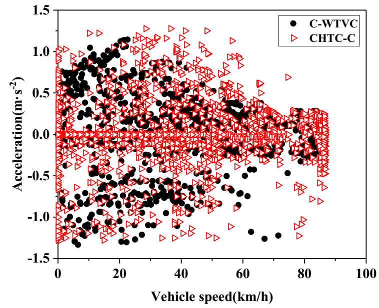
Fig. 15. The fuel consumption maps of the vehicles under C-WTVC and CHTC cycles.

4.3 Analysis of driving acceleration

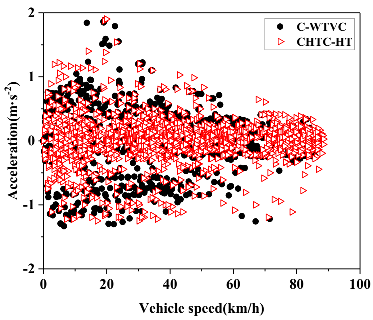
The driving acceleration maps of the vehicles under C-WTVC and CHTC cycles are shown in Figure 16. It can be found that the acceleration range of CHTC cycle is wider, and the gear which is the same as that of C-WTVC cycle cannot be used. During driving, it needs to downshift and speed up several times, and the fuel consumption will increase accordingly.



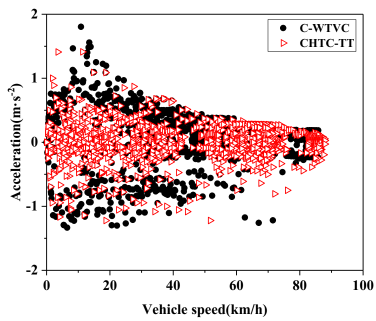
a) C-WTVC and CHTC-B cycles



b) C-WTVC and CHTC-C cycles



c) C-WTVC and CHTC-HT cycles



d) C-WTVC and CHTC-TT cycles

Fig. 16. The driving acceleration maps of the vehicles under C-WTVC and CHTC cycles.

5 Conclusion

This paper introduces the simulation method of calculating the fuel consumption of heavy-duty commercial vehicles based on VECTO, analyzes the differences between C-WTVC and four CHTC cycles by comparing the characteristic parameters, calculates the fuel consumption of four vehicles under C-WTVC and CHTC cycles with VECTO, compares the fuel consumption maps and driving acceleration maps of two cycles, and explores the influence of different test cycles on fuel consumption. The results show that the CHTC cycle has the characteristics of lower speed, higher idle speed, acceleration and deceleration, which is in line with the characteristics of high proportion of low speed and load of heavy-duty commercial vehicles in China. The fuel consumption of CHTC cycle is higher than that of C-WTVC cycle. And the higher acceleration and deceleration of CHTC cycle are the important reasons for the increase of fuel consumption.

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