Study on CO_2 Emission Characteristics of China Ⅵ Heavy Duty Diesel Engine

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Abstract. CO_2 emission control is of great urgency, and the decrease of heavy-duty diesel engines' CO_2 emission is one of the significant methods to reduce CO_2 emission. This paper uses a full-flow constant-volume dilution sampling system to experiment on the China VI heavy-duty diesel engine in order to measure CO_2 emissions under WHTC and WHSC cycles and different loads, with studying the instantaneous emissions characteristics of CO_2, post-processing effects on CO_2 emissions, influence factors of CO_2 emissions. The study found that the CO_2 emissions before the post-treatment of the WHSC cycle are 37% higher than that of the WHTC cycle, while emissions of CO_2 are 3.45% higher than that before post-treatment. Simultaneously, cold start increases the CO_2 emissions of the heavy-duty diesel engines by more than 1%. Post-treatment still increases the CO_2 emissions of heavy-duty diesel engines by 3.5%. In addition, CO_2 emissions have different trends with power at different speeds. CO_2 emissions get an incremental within 600rpm and 900rpm, which gradually becomes slower until it reaches the peak, as engine power increases; the CO_2 emissions initially increase, followed by a decrease, and then continue to increase within 1000rpm and 1400rpm; the CO_2 emissions are almost not affected by the speed within 1500rpm and 1900rpm.

Keywords: CO_2; China VI; Heavy Duty Diesel Engine; Emission Characteristics.

1. Introduction

The United Nations made a summary in October 2018, greenhouse gas emissions must be reduced by about half within 12 years.Only in this way is there the chance of maintaining the limit of global warming at 1.5°C [1] [2]. The contribution of CO_2 to the greenhouse effect accounts for about 50% of all greenhouse gases [3]. Since 2000, China's carbon emissions began to grow rapidly [4], which have reached 10.251 billion tons by 2000, and China have become the largest CO_2 emission country in the world (27.92%) [5]. On September 22nd, 2020, China proposed in the Seventy-fifth United Nations General Assembly: “Strive to reach the peak of CO_2 emissions before 2030, and strive to achieve carbon neutrality before 2060” .The “14th Five-Year Plan” clearly stated that reduce CO_2 emissions by 18% in the next 5 years. Therefore, it is imminent to reduce CO_2 emissions.

According to the 2014 National Greenhouse Gas List, the greenhouse gas of energy activities emits 9.559 billion tons of carbon dioxide equivalent, which is the largest source of greenhouse gas emissions in China, accounting for 77.7% of total greenhouse gas emissions. Greenhouse gas emissions of transportation are 820 million tons of carbon dioxide equivalent, accounting for 8.6% of greenhouse gas emissions of energy activities and 6.7% of the country’s total greenhouse gas emissions. Road transportation energy accounts for 84.1% of transportation greenhouse gas emissions, while medium and heavy commercial vehicles account for 47.1% of road transportation greenhouse gas emissions. Moreover, Forward Industry Research Institute sorted out "China Automobile Low Carbon Action Plan Research Report 2020", which showed that diesel fuel vehicles have the highest carbon emissions in unit mileage of vehicles with different fuel types in 2019, reaching 281.9g/km. In addition, the GB17691-2018 "Limits and Measurement Methods for Emissions from Diesel Fueled Heavy-Duty Vehicles (CHINA VI)", clearly stated that the specific requirements on CO_2 emissions would be suitable for publication, and stipulated that the engine standard cycle emission test should measure the CO_2 emissions of the engine, moreover, record the CO_2 specific emission value and the fuel consumption specific fuel consumption value of the cycle. Therefore, it is essential to study the CO_2 emission characteristics of heavy-duty diesel engines based on the China VI emission standards.

This paper studies via the following three points:

1) The instantaneous emission characteristics of CO_2 in the China VI Standard Cycle WHTC and WHSC.

2) The post-treatment route of China VI is EGR + DOC + DPF + SCR + ASC [6], but this technical route will convert conventional pollutants into CO_2 [7]. Therefore, the emission differences before and after post-treatment

are compared and analyzed, and analyze whether the CO_2 converted by other pollutants via the post-treatment route can be ignored at the current stage.

3) The influence law of different factors such as engine power, speed, excess air coefficient, etc. on CO_2 emissions of heavy-duty diesel engines are studied and analyzed.

2. Experimental Methods

The China VI emission standard recommends using full-flow dilution for emission test, moreover, constant-volume dilution sampling is closer to the actual application scenario where exhaust gas are discharged into the air in comparison with direct sampling [8]. Therefore, this experiment adopts the HORIBA full-flow constant-volume dilution sampling system. As shown in Fig.1, the diluted air is sampled after being mixed with the exhaust gas in the dilution channel through the filter unit, and the gas analyzer analyzes to obtains the measurement result.

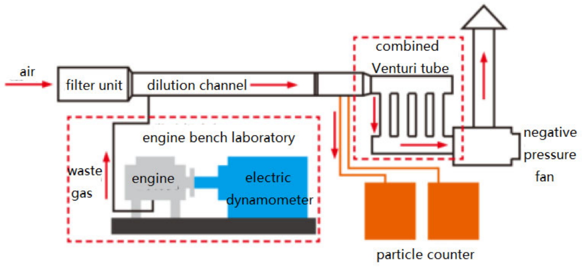


Fig. 1 HORIBA full-flow gas circuit diagram

WHTC and WHSC experiments were carried out based on China VI standards, the CO_2 emissions of original machine and post-treatment back end were measured, the experiment were repeated ten times and the results of the ten experiments were compared and analyzed.

In order to study the influencing factors of CO_2 emissions of China VI heavy-duty engines, the CO_2 emissions under stable working conditions were measured. Experiments were carried out based the China VI emission standards: (1) set the idle speed as the first working condition speed, and 0Nm as the first working condition torque; (2) first, keep the working condition speed unchanged and increase torque based on the 100Nm interval until the throttle is increased to 100%; (3) then increase the engine speed base on the 100rpm interval, and repeat step (2) until the speed reaches the maximum speed. At each working condition point, the bench data and the emissions of various pollutants are recorded based on point distance, and each point distance is recorded as the average value within 10s.

2.1 Experimental equipment

The experimental bench includes: AVL engine dynamomete, AVL 740 fuel consumption meter, AVL puma operating system, AVL air flow meter, Horiba gas analyzer, inlet air conditioning, full room air conditioning, intercoole and coolant temperature control system, PR3 oil return pressure control system, the specific parameters are shown in Table 1.

2.2 Experimental engine and fuel

The engine selects a heavy-duty diesel engine, which meets the test requirements of GB17691-2018 "Limits and Measurement Methods for Emissions from Diesel Fueled Heavy-Duty Vehicles (China VI)". The engine parameters are shown in Table.2.

The engine fuel selects China VI commercial diesel, the fuel information is shown in Table.3.

Table 1. Parameters of experimental equipment

experimental equipment	equipment model	equipment measurement range	accuracy
dynamometer	AVL ASM 3000/1.8-4.5	speed: 0-4500r/min torque: 0-3000Nm; power: 0-560kW	torque: ±0.3%F.S speed: ±1rpm
fuel consumption meter	AVL 740MF	(0-150)kg/h	≤±2% of flow setting value
air flow meter	AVL FLOWSONIXTM Air 150	20-1400 kg/h	/
direct sampling gas analyzer	HORIBA MEXA-ONE-DC-OV-OVN-25H	CO0-5000 ppm CO_2:0-20vol% NO/NOx:0-100000 ppm	Within 1.0%(Range≥155ppm)or Within 2.0%(Range≤155ppm)
xicai gas analyzer	HORIBA MEXA-ONE-DC-OV-OVN-35H	CO(L):0-5000 ppm CO_2:0-6vol% NO/NOx:0-5000 ppm	Within 1.0%(Range≥155ppm)or Within 2.0%(Range≤155ppm)

Table 2. Parameters of engine

number of cylinders	Displacement(L)	intake way	rated power (Kw)/speed (rpm)	maximum torque (Nm)/speed (rpm)	fuel requirement
6	12.94	charge inter-cooling	430/1900	2600/1000-1400	0# China VI fuel

Table 3. Parameters of fuel

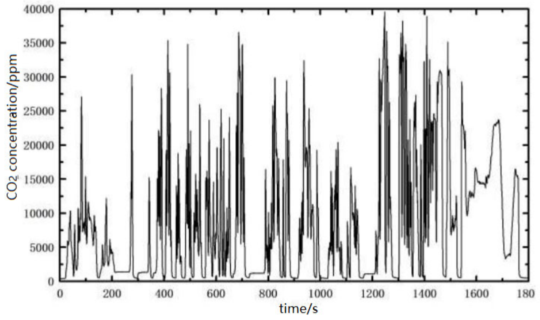
cetane number	cetane number index （Rating）	density (15°) (kg/m^2)	density (20°) (kg/m^2)	total aromatics (m/m)	kinematic viscosity (40°) (mm^2/s)
52.0	49.2	840.9	835.4	21.4%	3.974

3. Experimental Results and Analysis

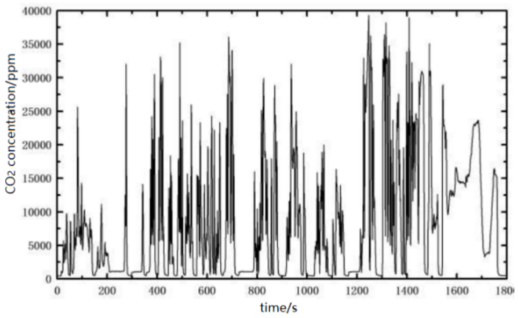
3.1 Research on the characteristic of CO_2 instantaneous emission

The China VI standard stipulates that the instantaneous test cycle WHTC and the steady-state test cycle WHSC are used for engine test. Therefore, this paper studies the characteristics of CO_2 instantaneous emission of WHTC and WHSC cycles.

As shown in Fig.2, the CO_2 concentration of WHTC cold and hot start cycles is between 0-40000ppm, and the peak value is between 1200-1500s. As shown in Fig.3, the CO_2 concentration of WHSC cycle is between 0-110000ppm, and the peak value is much higher than that of WHTC cycle.



(a) WHTC cold start cycle



(b) WHTC hot start cycle

Fig. 2 CO_2 instantaneous emission trend of WHTC cycle

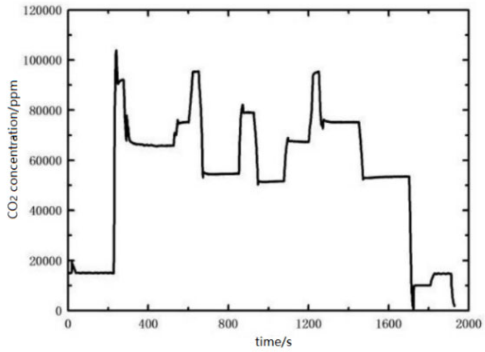


Fig. 3 CO_2 instantaneous emission trend of WHSC cycle

3.1.1 Contrast studies of WHTC and WHSC cycle emission

The instantaneous emission mass is calculated by the original concentration and exhaust mass flow of pollutants arranged based on conversion time. The instantaneous value of the whole cycle is integrated, and in order to obtain the pollutant mass emission, the integration is multiplied by the ratio of exhaust component to exhaust density, as shown in equation (1) [9].

$$m_{gas} = u_{gas} \times \sum_{i=1}^{i=n} c_{gas,i} \times q_{mew,i} \times \frac{1}{f} \ (unit：g \ / \ test) \quad (1)$$

In the equation, u_{gas} is the ratio of exhaust component density to exhaust density; $c_{gas,i}$ is the instantaneous concentration of exhaust component, ppm; $q_{mew,i}$ is the instantaneous exhaust mass flow, Kg/s; f is the sampling frequency, Hz; n is the number of tests.

As shown in Fig.4, at the front of the engine post-treatment, the CO_2 of the WHSC cycle engine tops 37131g, and the WHTC cycle tops 26177g. After averaging the results of ten experiments, the CO_2 emissions of WHSC cycle are 37% higher than weighted CO_2 emissions of WHTC cycle in hot and cold states, and the CO_2 specific emissions of WHSC cycle are 3.45% greater than weighted CO_2 emission of WHTC cycle in the cold and hot states, as shown in Fig.5. Because the WHSC cycle is the steady-state cycle, the combustion in the cylinder is fuller.

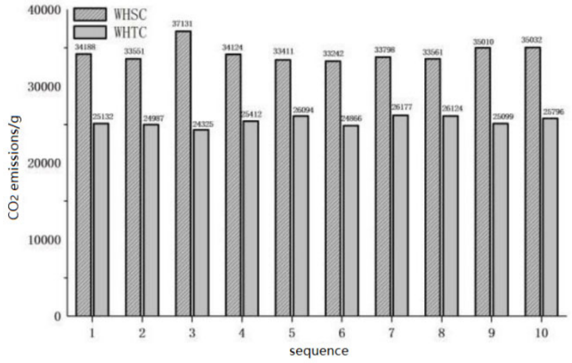


Fig. 4 comparison of CO_2 emissions of WHSC and WHTC cycles at the front of post-treatment

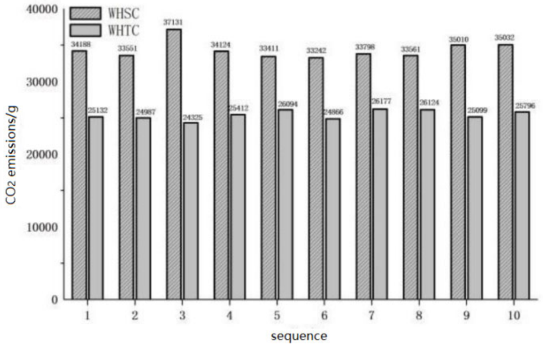


Fig. 5 comparison of CO_2 specific emissions of WHSC and WHTC cycles at the front of post-treatment

3.1.2 The impact of cold start condition on CO_2 emissions of heavy-duty diesel engines

As shown in Fig.6, at the front of the engine post-treatment, the CO_2 emissions of WHTC in cold state are 1.09% larger than that in hot state, which suggests that cold start condition will increase CO_2 emissions of heavy-duty diesel engines. Because the combustion is not full during cold start, however, the increase of fuel injection quantity plays a decisive role and causes the increase of CO_2 emissions.

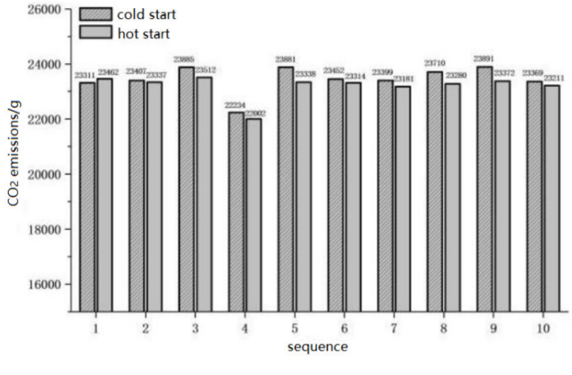


Fig. 6 comparison of CO_2 emissions of WHTC cycle in hot and cold states at the front of post-treatment

3.2 The impact of post-treatment on CO_2 emissions

As shown in Fig.7, the CO_2 specific emissions after post-treatment are 3.5% larger than that before post-treatment on average. Because DOC oxidizes unburned HC to CO_2.

Moreover, DOC oxidizes the diesel fuel injected into the exhaust pipe with released heat, which increases the temperature of the DPF. And the carbon in DPF can react with oxygen to generate CO_2. In addition, the hydrolysis reaction of urea in SCR can also generate CO_2 [10]. This post-treatment technology of heavy-duty diesel engine increases CO_2 emissions while reducing conventional pollutants.

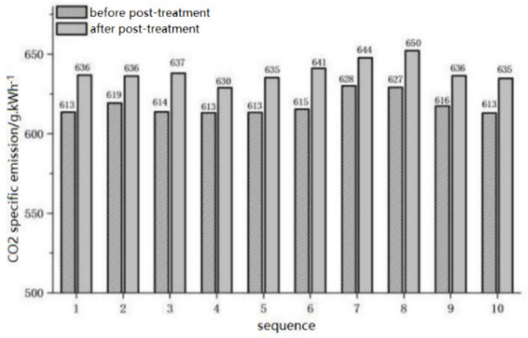


Fig. 7 comparison of CO_2 specific emissions before and after post-treatment

3.3 The impact of different factors on CO_2 emissions of heavy-duty diesel engines

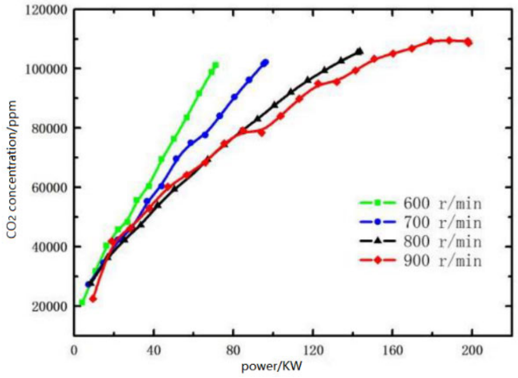
3.3.1 The impact of power and speed on CO_2 emissions of heavy-duty diesel engines

As shown in Fig.8, the CO_2 emission concentration of engine is in the range of 2000-11000ppm. In the range of 600rpm-900rpm, the CO_2 emission concentration can reach 11000ppm at 200KW, while in the range of 1000rpm-1400rpm, the CO_2 emission concentration can reach maximum value at 300KW, and in the range of 1500rpm-1900rpm, the CO_2 emission concentration can reach maximum value at 400KW. Since CO_2 emissions show varied laws in different speed ranges, it is necessary to study separately.

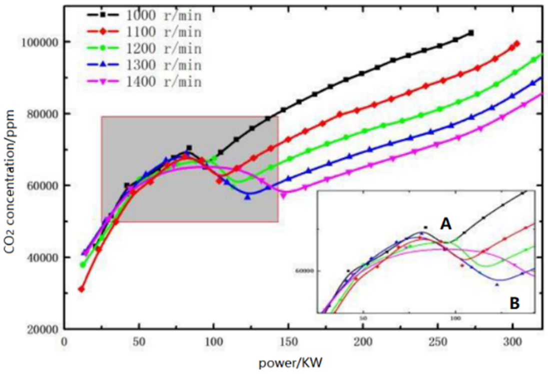
As shown in Fig. 8(a), when the engine speed is between 600rpm-900rpm, CO_2 emissions increase with the increase of engine power, but the increasing trend gradually becomes slower and does not increase until it reaches the peak value. Moreover, at the same power, the higher the speed, the smaller the CO_2 emissions. As the load increases, the amount of fuel injection quantity increases, resulting in the rise of CO_2 emissions. However, due to the increase of the load, the oxygen concentration will decrease and the fuel injection duration will increase, so the reaction time of the fuel injected later is shorter with the result that the combustion is not full. Therefore, under the combined effect of the fuel injection quantity, the increasing trend of CO_2 emissions is gradually slowing down. Moreover, the higher the speed, the shorter the mixing and combustion time, and the combustion is not easily full, so the CO_2 emissions are smaller.

As shown in Fig. 8(b), when the engine speed is between 1000rpm-1400rpm, CO_2 emissions increase steadily and the differences of CO_2 emissions at different speeds are not obvious before 90KW. But between 90KW and 130KW CO_2 emissions start to decline, and then continue to rise. Meanwhile the higher speed, the smaller the CO_2 emissions. Therefore, there are two turning points between 1000rpm-1400rpm: the turning point A from increase to decrease and the turning point B from decrease to rise. Turning points A are relatively close at different speeds, and there is no obvious law. Turning points B shift below and behind as the speed increases. Namely, the greater the speed, the greater the reduction of CO_2 emissions and the wider the reduced power range.

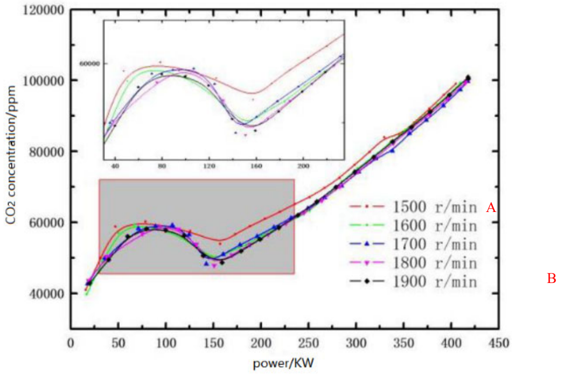
As shown in Fig.8(c), when the engine speed is between 1500rpm-1900rpm, the development law of CO_2 emissions is similar to that of 1000rpm-1400rpm. However, the changing curves of CO_2 emissions with power at different speeds basically coincide. Therefore, the CO_2 emissions of the engine are less affected by the speed between 1500rpm and 1900rpm.



(a) 600rpm-900rpm



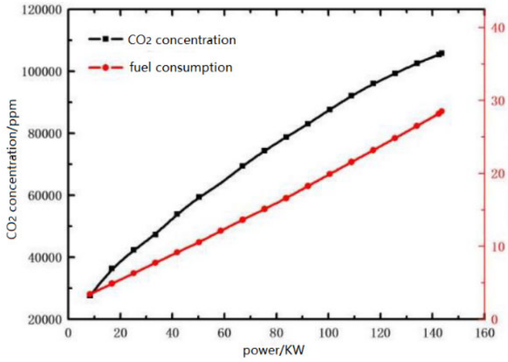
(b) 1000rpm-1400rpm



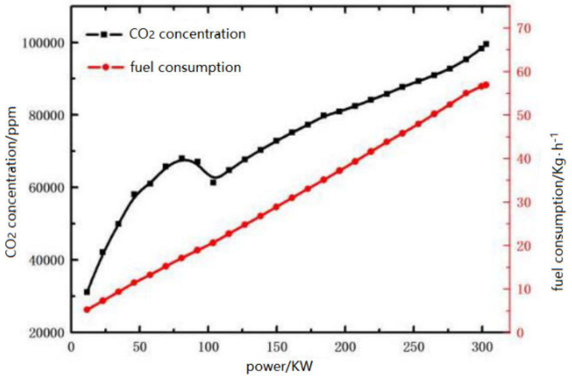
(c) 1500rpm-1900rpm

Fig. 8 the relationship between CO_2 and power and speed

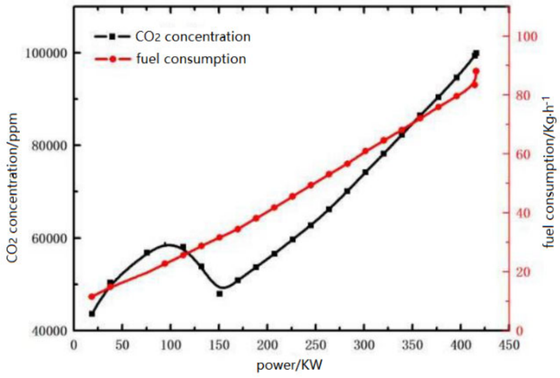
In order to avoid the influence of differences of ECU control strategy on the above laws, namely, the influence of the differences of fuel injection quantity at different loads on the above laws, compare the CO_2 emissions and the fuel consumption with power of heavy-duty diesel engines in three speed ranges. As shown in Fig.9, the fuel injection quantity of this engine increases linearly with the increase of power, but CO_2 emissions with power still have turning points within 1000rpm-1400rpm and 1500rpm-1900rpm. Therefore, in the 600rpm-900rpm, fuel consumption plays a leading role in CO_2 emissions, in the 1000rpm-1400rpm and 1500rpm-1900rpm, in addition to the impact of fuel consumption on CO_2 emissions, load also has an impact on CO_2 emissions, its influence mechanism will be studied as the content of the next stage.



(a) 600rpm-900rpm



(b) 1000rpm-1400rpm



(c) 1500rpm-1900rpm

Fig. 9 CO_2 emission and fuel consumption change with power

4 Conclusion

This paper carries out experiments on the China VI heavy-duty diesel engine with full-flow constant-volume dilution sampling system, measuring the CO_2 emissions of the WHTC and WHSC cycles and different loads of engine, after processing the data. The following conclusions are drawn:

(1) At the front of engine post-treatment, the CO_2 emissions of the engine WHSC cycle are 37% higher than the weighted CO_2 emissions of WHTC cycle in the cold and hot states. Moreover, the CO_2 specific emission of engine WHSC cycle are 3.45% greater than the weighted CO_2 specific emission of WHTC cycle in the cold and hot states.

(2) At the front of engine post-treatment, the CO_2 emissions of WHTC in cold state are 1.09% larger than that in hot state. Therefore, cold start conditions will increase CO_2 emissions of heavy-duty diesel engines.

(3) The CO_2 specific emission after post-treatment are 3.5% larger than the CO_2 emissions before post-treatment on average.

(4) When the engine speed is between 600rpm-900rpm, CO_2 emissions increase with the increase of engine power, but the increasing trend gradually becomes slower and does not increase until it reaches the peak value. Moreover, at the same power, the higher the speed, the smaller the CO_2 emissions. When the engine speed is between 1000rpm-1400rpm, CO2 emissions increase steadily and the differences of CO2 emissions at different speeds are not obvious before 90KW. But between 90KW and 130KW CO2 emissions start to decline, and then continue to rise. Meanwhile the higher speed, the smaller the CO2 emissions. So the greater the speed, the greater the reduction of CO_2 emissions and the wider the reduced power range. When the engine speed is between 1500rpm-1900rpm, the development law of CO_2 emissions is similar to that of 1000rpm-1400rpm. However, the changing curves of CO_2 emissions with power at different speeds basically coincide. Therefore, the CO_2 emissions of the engine are less affected by the speed between 1500rpm and 1900rpm.

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