Trends in Renewable Energy
OPEN ACCESS ISSN: 2376-2144
Peer-Reviewed Review Article futureenergysp.com/index.php/tre

A Review of Engine Emissions Testing Methods for Environmental Sustainability

Minghao Wang*

School of Mechanical Engineering/Institute of Vehicles and New Energy Technology, North China University of Water Resources and Electric Power, Zhengzhou City, Henan, China

Received February 25, 2022; Accepted March 23, 2022; Published March 28, 2022

With the increase of vehicle ownership, vehicle emission pollution has become a major source of air pollution. The control of automobile pollutant emissions is one of the effective methods to reduce air pollution. Domestic and foreign exhaust pollutant testing methods for in-use vehicles have been gradually developed from the original idling method to the double-idling method and the simple working condition method. There are many methods to test the exhaust pollutants of in-use vehicles, but the test operation cycle, gas analysis principle, cost, application occasions and the accuracy level of various testing methods are different. This paper introduces the idling method, the working condition method and the on-board emission testing method for detecting vehicle emission pollutants. Two optimized methods for detecting automotive emission pollutants (namely the double-idle method and the simple transient working condition method) are also introduced.

Keywords: Emission characteristics; Detection methods; Air pollution; Idling method; Working condition method; On-board emission testing method

Introduction

In recent years, with the continuous development of the automobile industry and the increase of the average gross national product (GNP), the number of vehicles is also growing. In 2015, the number of motor vehicles in China was 273 million, of which 172 million were cars, accounting for 61.65%. By 2020, the number of motor vehicles in China reached 372 million, and the number of cars in China reached 281 million in 2020, accounting for 75.54%. In the past five years, China's car ownership has increased by 63.4% year-on-year. There are 70 cities in China with more than 1 million cars. There are 31 cities with more than 2 million vehicles and 13 cities with more than 3 million vehicles, including more than 5 million vehicles in Beijing, Chengdu and Chongqing, and more than 4 million vehicles in Suzhou, Shanghai and Zhengzhou. All these data can clearly show that China's car ownership has been showing a very rapid growth trend. In the process of the rapid growth of car ownership, the emission and concentration of automobile pollutants are also gradually increasing, which will cause serious pollution to urban air quality. So, the problem of urban air pollution caused by car emissions has become very serious [1].

Gasoline engine emissions mainly include hydrocarbons, carbon monoxide and nitrogen oxides. In order to solve the problem of automobile emission pollution, scholars in various countries have shifted their research focus to alternative fuels. At present, the

*Corresponding author: wang22310@ 163.com

Tr Ren Energy, 2022, Vol.8, No.2, 96-106. doi: 10.17737/tre.2022.8.2.00141

main alternative fuels include methanol, ethanol, hydrogen, natural gas and dimethyl ether. It was found that the mass fraction of C atom in methanol and ethanol branches was small, which could reduce CO and soot emissions. Moreover, the high oxygen content in methanol and ethanol is more conducive to promoting the complete combustion of fuel, saving fuel, and greatly improving the exhaust emission performance, with the average reduction of CO and CH compounds by more than 30% **Error! Reference source not found.**, [3]. The high vaporization latent heat of methanol can reduce the combustion temperature, reduce the formation of NO_x compounds, and improve the methanol ratio to obtain better combustion and reduce the formation of HC, CO and soot [4]. However, with the increase of methanol blending ratio, NO_X emission also increases significantly [5]. Compared with gasoline, CO, HC and NO_x emissions of ethanol-blended gasoline fuel are significantly reduced **Error! Reference source not found.**. However, with the increase of ethanol mixing ratio, NOx emission decreases, and CO and HC emissions increase [7]. This makes the engine emission test technology extremely important. A good test method can improve the accuracy of test results and provide a theoretical basis for the control of vehicle emissions.

China is the world's second largest economy. China's economic development has made great achievements in the past decade. At the same time, severe haze occurs frequently in the country, especially in areas with high economic growth. According to monitoring data from China's Ministry of Ecology and Environment, the number of haze days in 74 pilot cities with new air standards accounts for 25% to 50% of the year and is on the rise. Motor vehicle emission standard I was uniformly implemented nationwide in 2000, and motor gasoline standard I and diesel standard I were implemented in 2001 and 2003, respectively. Emission standards have been continuously improved since then. In 2019, the gasoline standard VI and diesel standard VI were implemented [8]. And good exhaust gas testing emission methods can reduce the error of engine emission test values and improve the rate of engine development and improvement.

Different emission testing methods have different emission limits. In order to truly and accurately screen and identify urban high-emission and high-polluting vehicles, the correlation between the emission limits of each testing method should continue to be studied to achieve effective control of motor vehicle emissions.

Emission Testing Methods

The exhaust of an engine contains harmful gases, liquid particles and solid particulate components. The measurement of harmful gas components such as CO_2, HC, NO_X, SO, etc. in the exhaust gas is usually analyzed in engine testing as exhaust gas analysis, while the measurement of visible pollutants contained in the exhaust gas is called smoke measurement or exhaust visible pollutant measurement.

Contaminant Detection Methods

The test methods for the emission of pollutants from automobiles are divided into two types of test methods, *i.e.,* the idling method and the working condition method.

Idle Speed Detection Method

The idling method is a method of measuring exhaust pollutants from a vehicle at idling conditions, generally measuring only CO and HC, and using a portable emission analyzer as the measuring instrument. This method has the advantages of simplicity, cheap and portable measuring device, and short testing time. However, the disadvantage of the idling method is the lack of comprehensive representation of the measurement results. Idle speed method can be used as the environmental protection department of the in-use vehicle emissions testing, as well as a comprehensive automotive repair shop on the vehicle emissions performance and whether the engine is working properly for a simple evaluation method, can not be used as the engine factory emissions measurement standards. It cannot be used as an emission measurement standard for the engine [9].

Working Condition Test Method

The working condition method combines a number of common working conditions of a vehicle and the more polluting working conditions for pollutant emission measurement, with a view to evaluating the vehicle emission level comprehensively. At present, there are three major systems of emission regulations in the world, namely, the United States, Japan and the European system. Other countries basically develop their own emission regulations on the basis of the United States and European regulations.

Compared with the idling method, the working condition method can reflect the level of vehicle emissions more comprehensively, which is generally used for the certification of new vehicles and factory sample testing. But the price of its test equipment is often 100-200 times more than the portable emissions analyzer for the idling method. The main equipment used for vehicle emission pollutant testing by the working condition method includes an exhaust sampling system, chassis dynamometer, gas flow analyzer, automatic detection control system, and five gas analyzers. The actual test is carried out by first pre-testing the vehicle to verify the basic conditions of the vehicle and ensure that the vehicle is suitable for emission pollutant testing by the working condition method.

Vehicle-borne Emission Testing Methods

Vehicle exhaust testing using a Portable Emissions Measurement System (PEMS) is called Vehicle Emissions Testing. It is directly installed on the car driving on the road, effectively collects various parameters and pollutant emission conditions during the driving process of the vehicle, and clearly expresses the pollutant emission status in the driving process of the vehicle. High sensitivity, good vibration resistance and high sensitivity are the direct advantages of this detection method. This detection method is very widely used [10].

The PEMS system can directly measure the exhaust gases of a vehicle, including CO, CO2, HC, NO_X, and particulate matter, as well as the vehicle's driving recorder, location information and speed. The analyzer uses the specificity of the infrared wavelength electromagnetic energy of different gases to further detect pollution levels.

Exhaust Gas Sampling Methods

Direct Sampling Method

The direct sampling method is to insert the sampling probe directly into the engine exhaust pipe which uses the sampling pump to take a certain amount of gas sample directly for feeding into the water separator. The water separator is generally composed of a condenser and a drainage device, which is used to condense and dehumidify the exhaust gas sample, and prevent the interference of the moisture in the exhaust gas sample to the exhaust gas analyzer. After the coarse filter and fine filter, the dust, solid particle contaminants and liquid particle contaminants in the gas are filtered out. The exhaust gas needs to be dried. As shown in Figure 1, to prevent coalescence and adsorption of HC and other components in the sampling tube, the lower concentration specimen pipeline can be separated and the pipeline system can be heated to 140°C for measuring HC content in gasoline engine exhaust, and 180-200°C for diesel.

The direct sampling method is simple and easy to use, which can be flexibly applied to all operating conditions. It is suitable for continuous observation of changes in exhaust composition due to variable operating conditions. As a standard sampling method, the direct sampling method is widely used in bench tests and idle measurements of heavy vehicles.

However, the adsorption phenomenon in the sampling line of the direct sampling method can cause measurement errors. In order to remove water vapor from the sample gas, a condenser and other devices are required in the sampling system, but condensation tends to coagulate substances with high boiling points in the exhaust gas. Since the operating temperature of the condenser is different, the measured HC concentration will vary.

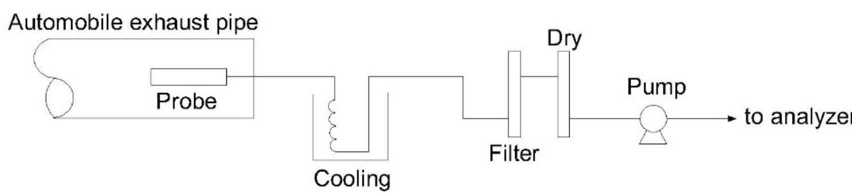

Figure 1. Direct sampling exhaust gas analyzer

Constant Volume Sampling Method

The constant volume sampling method is also known as variable dilution sampling, and there are three common types of variable dilution sampling devices: constant volume samplers with positive displacement pump (PDP-CVS), constant volume samplers with critical flow venturi (CFV-CVS), and constant volume samplers with controlling stable flow by volume orifice (CFO-CVS). The CFV system is less affected by temperature and is relatively simple. However, changing the total flow requires replacing the Venturi tube, and the total flow of the system can only be changed in stages.

Emission regulations around the world now require sampling with a constant volume sampling (CVS) system. A typical exhaust gas analyzer measures the concentration of the component in the exhaust and then calculates the total emission of the component based on the exhaust flow. This needs to be achieved with the engine in steady state operation. In a non-steady state, the measured concentration curve and the exhaust flow curve can theoretically be integrated over time to calculate the total. However, in actual operation, this can lead to large errors due to the variation of exhaust pressure with operating conditions, differences in the dynamic response lag of the sampling system and the measuring instrument, and the fact that the mixture concentration curve of the sampled gas does not reproduce the temporal characteristics of the engine emissions [11] .

So, the researchers used a method of measuring the average to solve the problem. The most intuitive way to do this is to collect all the exhaust gas from 1 standard test cycle into an air bag. Then, the concentration of each pollutant in the air bag is measured at the end of the test cycle and multiplied by the total amount of diluted exhaust that flowed through the CVS system to get the total amount of each pollutant in the engine during the measurement.

The constant volume sampling method is a sampling method that approximates the actual state of vehicle exhaust diffusion into the atmosphere. After dilution with air, it is ensured that the density of the diluted gas remains constant at a constant temperature. A fixed volume flow of the sample gas is then sent to atmosphere by the action of a constant volume pump. There is a strict proportionality between the sample gas and the flow rate of the constant volume pump. The constant volume sampling method prevents water vapour condensation due to sufficient dilution to contain the interaction between the emission components. However, if the dilution is too strong, the concentration of pollutants in the diluted sample gas will be too low, causing problems such as insufficient sensitivity of the measurement analyzer.

The constant volume sampling method has two systems of CVS-1 and CVS-3. The CVS-1 uses only one type of sampling bag, while the CVS-3 sampling system uses three sampling bags, allowing for three separate samples for the cold start, stable operation, and hot start phases.

Full Volume Sampling Methods

The full volume sampling method involves collecting the entire exhaust from an engine exhaust test into a bag with sufficient volume for analysis [12]. This sampling method allows both the determination of the average concentration of exhaust pollutants and the calculation of emissions. From the time the sample gas is introduced into the bag to the final measurement, it is very likely that HC will be adsorbed in the bag, that reactive components of HC will react or polymerize with each other, and that NO_x will be oxidized. In order to prevent the condensation of water vapor in the sample gas in the bag, the sample gas is cooled with 10-15°C water before entering the bag through a thermal interactor, so the HC with high boiling point is also easily condensed and dissolved in water and then released, causing certain errors.

Optimized Emission Gas Detection Methods

Double Idle Method

The exhaust pollutant testing methods for in-use vehicles have been gradually developed from the original idling method to the double-idling method in China and abroad [[13]. It is a method to measure the volume concentration of CO and HC in the exhaust of in-use vehicles under idling conditions and high idling conditions (*i.e.,* 50% of rated speed). It is proposed by the International Organization for Standardization in ISO3929 and generally accepted by all countries. In the emission regulations for in-use gasoline vehicles promulgated by the China State Ministry of Environmental Protection, the double-idling method is used as the basic measurement method, which is equivalent to the standard of the EU Regulation 92/55/EEC. The main pollutants measured by the dual-idle method are CO and HC, and China Standard GB8285-2005 requires the use of a Non-Dispersive Infrared (NDIR) analyzer for measuring pollutants by the dual-idle method. The main advantages of the dual idle measurement are that it has low requirements on test instruments, is easy to use, and has a certain recognition rate for high emission measurements [14].

Both the idling method and the double-idling method have the following problems in actual use: (1) The idling and double-idling methods will achieve good results in testing old, technologically outdated vehicles. However, when testing electronically controlled vehicles (such as vehicles equipped with three-way catalytic converters and oxygen sensors), the recognition rate of high pollution measurements is not high. This is because, when the efficiency of the three-way catalytic converters decreases, the idling conditions with relatively low speed of conversion efficiency may still be high, while the conversion efficiency drops sharply for medium and large loads at relatively high RPM. (2) The idle speed method and double idle speed method are not suitable for testing NO_X emissions. The reason is that at idle speed or high idle speed, NO_X emission is small and difficult to detect. (3) The idle speed method and double idle speed method only test the unrepresentative working condition of the car, which cannot reflect the actual working emission of the car. (4) The idle speed method and double idle speed method leave opportunities for carburetor cars to cheat. The owner can lower the mixture concentration by adjusting the carburetor idle speed screw and throttle screw before the test, deviating from the normal idle concentration mixture design state. After passing the test, in order to ensure the smooth start of the vehicle, the operation can be reversed to the original state. (5) The correlation between the idle speed method or double idle speed method and working condition method is poor, and the identification rate of high emission vehicles is relatively low.

Simple Transient Service Method (VMAS)

In gasoline vehicle exhaust testing, both the simple transient condition method and the double idling method require the use of gas analyzers to analyze pollutant concentrations. The simple transient condition method uses five gas analyzers (HC, CO, CO_2, O_2, NO), and the double idling method uses four gas analyzers (HC, CO, CO_2, O_2). The gas analyzer is an important piece of equipment for gasoline vehicle exhaust testing and has a direct impact on the accuracy of the test results, and its routine calibration/inspection is an effective means to ensure equipment compliance and result accuracy. The daily calibration/check is an effective means to ensure the compliance of the equipment and the accuracy of the results [15].

The simple condition method is divided into simple steady state loading condition method and simple transient condition method. The steady state loading condition method mainly checks the HC, CO, CO_2 and NO levels of gasoline vehicles while driving. If the emission concentrations of each pollutant are within the limits specified in the standard, the vehicle's test results can be considered as qualified. The transient condition method not only tests the above gases with the analyzer, but also takes into account O_2, and the test is done with the participation of a gas flow meter.

The VMAS sampling system for the simple transient condition method can be divided into two parts: One part extracts a small amount of raw emission gas and sends it to the five gas analyzer. The other part extracts the remaining vehicle exhaust after dilution by ambient air and sends it to the gas flow analyzer. After the gas flow analyzer is tested and converted to a standard state flow rate for the dilution flow rate, the original emission gas volume flow rate is calculated as follows.

$$V_R = V_d \times \eta \tag{2.2.1}$$

where: V_d-volumetric flow rate of diluted emission gas; η-dilution ratio, and

$$\eta = \frac{O_a - O_d}{O_a - O_r} \tag{2.2.2}$$

where: O_a-oxygen content in the environment; O_d-diluted oxygen content; O_r-original oxygen content.

The system finally takes the emission gas concentration measured by the five-gas analyzer and the raw emission gas flow rate and runs it through the VMAS microprocessor to obtain the mass emission value of the pollutant per second, *i.e.,*

$$m_n = C_m \times \rho_{rn} \times V_r \tag{2.2.3}$$

where m_n-mass of emission, g/s; C_{rn}-volumetric concentration of the n^{th} substance (CO, CO_2, O_2, HC, NO_x) in the original exhaust; ρ_{rn}-density of the n^{th} substance in the original exhaust; V_r-volumetric flow rate of the original exhaust gas.

The system calculates the mass of each vehicle's exhaust pollutant on a second-by-second basis according to the above formula during the test, integrates it to obtain the mass of each emission during the entire test cycle, and divides it by the mileage of the test cycle to obtain the emission of each vehicle's exhaust pollutant (g/km).

The routine calibration/checking of the five gas analyzers can have an impact on the results of the simple transient service method [16]-[18]. For example, the accuracy of the five-gas analyzer, the accuracy of the standard gas and the pressure of the standard gas will have an adverse effect on the results of the simple transient method. Taking the standard gas pressure as an example, the five-gas analyzers used in Guangzhou, China are mainly controlled at 0.02 MPa and 0.1 MPa, which control the gas flow into the gas chamber under the limited pressure in line with the equipment set requirements (general flow requirements for about 20 mL/s). If the incoming air pressure does not match the specified air pressure, the calibration/check result will be inaccurate. If the incoming gas pressure is too low, the device response time is too long and the measured value is low. When the incoming gas pressure is too high, some devices have high measured values and the gas consumption is high.

Both the double-idling method and the simple transient working condition method can be used to screen high-emission vehicles. Under the respective determination conditions, the pollutant emissions per unit driving mile of the exceeded vehicles are much higher than those of the attained vehicles, while the pollutant emissions per unit driving mile of the exceeded vehicles of the VMAS are about 1.5 times of those of the exceeded vehicles of the double-idling method. There are still some vehicles with smaller pollutant emissions per unit mile traveled in the double-idling method, and they are at the emission level of the attainment vehicles, which means that the vehicles screened by the simple transient method are really high-emission vehicles. The screening results are more accurate and reasonable, and the results are more obvious when applied to in-use motor vehicles [19], [20].

Acceleration Simulation Mode (ASM)

In order to meet the emission control requirements for NO_x, a loaded test method is required. The simplest loaded test method is the ASM (Acceleration Simulation Mode) steady-state method, which is a combination of two steady-state conditions, 5025 and 2540, developed by the Southwest Research Institute and Sierra Research Institute in California, USA, in 1988. China's emission standards propose the use of ASM as a simple working condition method for in-use vehicle exhaust testing, which includes ASM5025 and ASM2540 two typical equal-speed loaded operating conditions.

(1) 50% of the output power at the ASM5025 operating test speed of 25 km/h and acceleration of 1.475 m/s^2 (the maximum acceleration in the FTP-75 cycle) is used as the loading power. For practical convenience, the standard provides for loading at the base mass of the test vehicle, when the loading power P5025 = base mass of the vehicle/148.
(2) 25% of the output power of the ASM2540 at a working test speed of 40 km/h and an acceleration of 1.475 m/s^2 is used as the loading power. In practice, the vehicle is loaded at its base mass and the loading power P2540 = base mass of the vehicle/185.

ASM is a load test, which can measure and discriminate the NO_x emission of vehicles, and is better than the idling method or double-idling method in identifying high-emission vehicles. However, the test conditions of the ASM method are at only two vehicle speeds, which are still different from the emission conditions when the vehicle is actually driving. Even if the emissions under these two working conditions pass, it does not guarantee that the emissions under other working conditions also pass. Moreover, the proportion of acceleration and deceleration conditions with poorer emissions in the actual use of the vehicle is larger, so this method cannot determine the superiority or inferiority of emissions during acceleration and deceleration.

Another shortcoming of the ASM is that the method is based on pollutant emission concentrations rather than emission masses. A vehicle with a small engine displacement emits less mass and a vehicle with a larger displacement emits more mass. But it is possible that the emission concentrations are the same. The ASM is thus unfair to vehicles with different engine displacements.

Transient Working Condition Method

IM240 Transient Operating Conditions

The IM240 test condition uses the two peaks of the first 0 to 333 seconds of the Federal Test Procedure (FTP) curve of the U.S. federal test protocol for new car type certification, which has been shortened to 240 seconds with modifications. The operating principle of the test equipment is the same as that required for the new vehicle test. The sampling device and analytical instrumentation are consistent with the new vehicle test. The sampling system is Constant Volume Sampling (CVS). The analytical instrumentation was a Non-Dispersive Infrared (NDIR) analyzer for CO, a Hydrogen Flame Ion Analyzer (FID) for HC, and a Chemiluminescence Analyzer (CLA) for NO_x. The final test results are expressed in g/km.

The IM240 characteristic test results have good correlation with FTP results. The correlation factors for the three pollutants can reach: 91.8% for CO, 94.7% for HC, and 84.3% for NO_x. At the same time, the dispersion of the IM240 test results for the three pollutants relative to the FTP results is small, so the misclassification rate of IM240 is low. IM240 is a highly technical test method, with expensive equipment, more complicated maintenance, longer testing time, and higher requirements for the testers.

IM195 Transient Operating Conditions

The China State Ministry of Environmental Protection has proposed IM195 transient condition in the new in-use vehicle emission standard, which is exactly the same as the first cycle condition in the first stage of the new model type certification condition specified in China Standard GB18352.1-2001 "Emission Limits and Measurement Methods for Light Duty Vehicles (I)" with a cycle test time of 195s (hence named as IM195). It contains a total of 15 working conditions, such as idle speed, acceleration, deceleration, steady speed, etc., which comprehensively simulates the driving conditions of the vehicle on the road. The test condition curves are shown in Figure 2.

The profile lines in Figure 2 indicate the gear change. The solid line is the theoretical operating condition line, and the dashed line is the actual operating curve of the tested vehicle. Except for the test cycle, the transient conditions IM195 and IM240 use exactly the same gas analysis principles and exhaust gas sampling system.

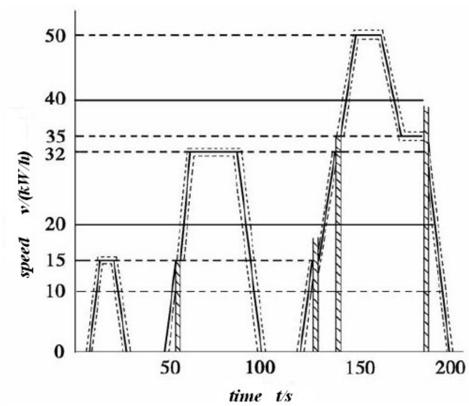

Figure 2. Transient working condition method (IM195)

CONCLUSION

A series of exhaust testing methods for in-use gasoline vehicles are briefly discussed, which includes the no-load idling method, the double-idling method, the loaded method with ASM steady-state operating conditions [21] and VMAS simple transient condition method. Some cities in China (such as Shenyang, Fushun, Anshan, Qingdao, and Shenzhen) have implemented the load test methods for in-use gasoline vehicles, including ASM and IG195 test methods. The advantages and disadvantages of these different test methods can be summarized as follows.

(1) The idling and double-idling methods do not reflect the actual emissions of the vehicle being driven and are not suitable for use in heavily polluted cities.

(2) The investment of ASM method equipment is low, the technology is mature, and the equipment of ASM method can be upgraded to VMAS equipment. So, it is reasonable to apply ASM testing method at this stage.

(3) The investment of VMAS equipment is medium, and the correlation between the test accuracy and the working condition method is good. The accuracy rate is high, and the error rate is only 5% or less (with the accuracy rate of IM240 being 100%). With the increasingly strict emission regulations, this test method will be the inevitable trend in the development of China's in-use vehicle exhaust testing methods.

(4) At present, the exhaust testing method used in China is basically equivalent to the methods used in Europe and the United States. It is the direction of further research to carry out the research on the working conditions of the exhaust testing curve of in-use vehicles, which is suitable for the actual situation of vehicles and the requirements of environmental protection in China.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this paper.

REFERENCES

[1] Wu, W. (2021). Analysis of the current situation of China's automobile emission control level and comprehensive countermeasures. *Internal Combustion Engine and Accessories,* 2021(5), 148-149. DOI: 10.19475/j.cnki.issn1674-957x.2021.05.069.
[2] Mohammed, M. K., Balla, H. H., Al-Dulaimi, Z. M. H., Kareem, Z. S., and Al-Zuhairy, M. S. (2021). Effect of ethanol-gasoline blends on SI engine performance and emissions. *Case Studies in Thermal Engineering*, 25, 100891. DOI: 10.1016/j.csite.2021.100891
[3] Yang, Z., Ge, Y., Wang, X., and Liu, J. (2020). Effect of Ethanol Gasoline on Emission Characteristics of China Sixth Direct Injection Gasoline Vehicle. *China Environmental Science,* 40 (12), 5213-5220. DOI:10.19674/j.cnki.issn1000-6923.2020.0575
[4] Zhou, D.Z., Yang, W.M., An, H., Li, J., and Shu, C. (2015). A numerical study on RCCI engine fueled by biodiesel/methanol. *Energy Conversion and Management,* 89, 798-807. DOI: 10.1016/j.enconman.2014.10.054
[5] Iliev, S. (2018). Comparison of Ethanol and Methanol Blending with Gasoline Using Engine Simulation. In (Ed.), *Biofuels - Challenges and oppor*tunities. IntechOpen. DOI: 10.5772/intechopen.81776
[6] Pan, J., Cheng, B., Tao, J., Fan, B., Liu, Y., and Otchere, P. (2021). Experimental Investigation on the Effect of Blending Ethanol on Combustion Characteristic and Idle Performance in a Gasoline Rotary Engine. *Journal of Thermal Science*, 30(4), 1187-1198. DOI: 10.1007/s11630-021-1487-33
[7] Rakopoulos, D. C., Rakopoulos, C. D., Kakaras, E. C., and Giakoumis, E. G. (2008). Effects of ethanol–diesel fuel blends on the performance and exhaust emissions of heavy duty DI diesel engine. *Energy Conversion and Management*, 49(11), 3155-3162. DOI:10.1016/j.enconman.2008.05.023
[8] Zhang, X. and Wang, Q. (2020). Study on the emission reduction effect of vehicle emission control policy in China. *China Population-Resources and Environment,* 30 (5), 98-109.
[9] Zhao, B. and Liu, X. (2017). Analysis of the detection method of automobile emission pollutants. *Automotive maintenance,* 2017(1), 4-8.
[10] Deng, Y. (2018). Detection methods for automotive emission pollutants. *Automotive Practical Technology,* 20, 58-60. DOI:10.16638/j.cnki.1671-7988.2018.20.020
[11] Wang, H.Y., Huang, C., Hu, Q.Y., Li, L., Chen, Y.H., and Xu, J. (2017). Emission correlation between simple transient operating condition method and constant volume full flow dilution sampling (CVS) method for light duty gasoline vehicles. *Environmental Science,* 38 (6), 2294-2300. DOI:10.13227/j.hjkx.201611139
[12] Wu, K.G and Cao, J.M. (2002). *Engine Testing Technology*, People's Traffic Press, Beijing.
[13] Wang, F. (2008). *Research on the testing methods and standards for exhaust pollutants of in-use gasoline vehicles*, Chang'an University, Thesis.

[14] China National Standards. (2005). *Limits and measurement methods for exhaust pollutants from vehicles equipped ignition engine under two-speed idle conditions and simple driving mode condition*. GB 18285-2005
[15] Yu, W.Y., Huang, Q.F., Huang, S.W., and Chen Q.H. (2015). Analysis of daily calibration/checking of five gas analyzers in simple transient working method and its influencing factors. *Analytical Instruments,* 2015(2), 74-79.
[16] Yu, Z., Xu, Z., Sun, L., and Bao, X. (2012). Study on emission degradation pattern of in-use vehicles. *Automotive Engine,* 2012(2), 63-65.
[17] Nong, J. and Shuang, J. (2010). A comparative analysis of double idling method and simple transient working condition method for exhaust gas detection of motor vehicles. *Environmental Engineering* 28(S1), 280-284. DOI:10.13205/j.hjgc.2010.s1.076
[18] Industry Standards - Environmental Protection. (2005). *The principle and method of confirm limits for exhaust pollutants from in-use vehicle equipped ignition engine under simple driving mode conditions*.
[19] Industry Standards - Environmental Protection. (2009). *Emission Limits for Exhaust Pollutants from Light Duty Vehicles with In-use Ignition Engines (Simple Transient Condition Method)*.
[20] Liu, X.H. and Zhu, X.P. (2014). Analysis of in-use motor vehicle exhaust emission detection methods. *Shanxi Electronic Technology,* 2014(4), 59-61.
[21] Wu, X. and Song, J. (2007). Research and development of in-use vehicle exhaust emission testing system with steady-state loading condition method. *Highway Traffic Technology,* 24(6), 131-138.