Impact of ethanol-gasoline implementation on vehicle emission based on remote sensing test

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Abstract

The vehicle exhaust remote sensing system was used to quantify the carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NO) concentrations of vehicles before and after the ethanol-gasoline implementation. The purpose was to investigate gasoline vehicle emissions for two distinct periods: before and after the ethanol-gasoline implementation. A comprehensive vehicle emission remote sensing data set collected in 2018 and 2019. The remote sensing test data was screened for duplicate vehicles in both two years. The average emission concentration of HC-CO-NO showed a continuous downward trend after ethanol-gasoline implementation. The three pollutant emission factors of small passenger cars are all lower than those of light trucks. Overall, the HC-CO-NO emission factors obtained through remote sensing tests have a small range of variation. From the results of the two-year test data, the emission levels of the 10% worst emission vehicles have shown a certain reduction compared with before the ethanol-gasoline implementation. Compared with random test errors of dynamometer emission test and portable emission measurement system, statistical results based on remote sensing test big data are more accurate.

1. Introduction

Faced with the energy shortage and environmental pollution problem, the automotive industry is under tremendous pressure. As a renewable biomass energy alternative to petroleum and natural gas, ethanol can relieve energy pressure and environmental pressure. Moreover, ethanol has relatively clean, green, and renewable characteristics, which has attracted the attention of many countries [1]. Ethanol-gasoline is a mixture of ethanol (C2H6O) and gasoline in a certain proportion, which has the advantages of high octane and good anti-knock performance [2]. Since 2003, Heilongjiang, Jilin, Shandong, Henan, Liaoning and other provinces in China have changed the gasoline to ethanol-gasoline (10%/90%) ethanol in succession. By 2020, ethanol-gasoline has achieved full coverage in China [3]. As a major producer and consumer of ethanol-gasoline, China has become the third largest market of ethanol-gasoline in the world after the United States and Brazil. After large-scale use of ethanol-gasoline, the characteristics of pollutants emitted by vehicles will also change to a certain extent.

Compared with traditional fossil fuels, the combustion of ethanol produces almost no pollutants. Ethanol-gasoline contains higher oxygen content, which can lead to more uniform combustion [4]. Due to the constant changes in the composition of gasoline and ethanol gasoline fuel, it is extremely important to understand the impact of new fuels on exhaust emissions. Previous studies have assessed the impacts of the use of ethanol-gasoline blends on pollutant emissions and energy consumption [5–7]. The results show that emissions of carbon monoxide and hydrocarbons decrease with the ethanol content increasing. With the increase in ethanol
content, nitrogen oxide emissions increased slightly, but this result is not consistent in the other research. The number of test vehicles in these studies is mostly a few samples, which cannot fully reflect the real-world vehicle emission changes before and after the use of ethanol-gasoline fuel.

Recently, with the rapid development of remote sensing test technology, the data accuracy of remote sensing testing of vehicle exhaust has reached the level of laboratory exhaust testing equipment [8]. Remote sensing test is a non-contact optical measurement technology. The infrared and ultraviolet beam transmitter is used to emit infrared and ultraviolet beam light. The exhaust fume emit from vehicles is passed through the infrared and ultraviolet beam. Based on the absorption degree of various spectra in the beam, carbon dioxide \((\text{CO}_2)\) is used as a reference gas to determine the concentration of carbon monoxide \((\text{CO})\), hydrocarbon \((\text{HC})\), nitrogen oxide \((\text{NO})\) and other gases in vehicle exhaust emissions [9]. Due to the highly portable and highly automated of remote sensing test equipment, an enormous amount of remote sensing test data can be obtained in a short time. Remote sensing test big data can be used to establish vehicle emission inventory, evaluate vehicle exhaust I/M system, screen high-emission vehicles, verify the emission model accuracy and so on.

The primary aim of this work is to investigate gasoline vehicle emissions for two distinct periods: before and after the ethanol-gasoline implementation. A comprehensive vehicle emission remote sensing data set collected in 2018 and 2019 of Tianjin. In China, for the first time, large-scale and long-term remote sensing test data were used to evaluate the changes in ethanol-gasoline emissions and provide a technical basis for the revision and implementation of ethanol-gasoline policies in the future.

2. Materials and methods

2.1. Remote sensing system

For our on-road remote sensing test, one remote sensing system was used to collect vehicle emissions data at roadside across Tianjin city from 2018 to 2019. As shown in figure 1, vehicle exhaust remote sensing system is mainly composed of Transmit and receive unit, Reflection unit, Vehicle speed measurement system, Meteorological monitor, Camera system and other systems. The remote sensing test host consists of a collinear

![Figure 1. The diagram of vehicle exhausts remote sensing system.](image-url)
UV/IR light source, which can send and receive infrared and ultraviolet detection beams, was a detector with non-dispersive infrared detection of CO, CO\(_2\), and HC and dispersive ultraviolet detection of NO. Infrared and ultraviolet light beams pass through the exhaust plume emitted by the vehicle tailpipe. Part light beam is absorbed by the exhaust gas, causing a change in the light intensity signal. Finally, the pollutant emission concentration in the actual driving state of the vehicle is obtained. The vehicle speed and acceleration were measured by the laser and radar. The camera system was used to capture vehicle license plate. The license plate can be used to identify the vehicle’s details registration data including fuel type, emission classification, model year and so on. Wind speed, wind direction, atmospheric pressure, temperature and humidity were obtained through the environmental meteorological monitor. The detection location should be in a non-downhill road with good view. In order to ensure that the remote sensing detection beam can cover sufficient vehicle exhaust smoke plumes, the slope of the detection section should be in the range of 0 to 5 degrees. In addition, the wind speed at the remote sensing test site must not exceed 5 m s\(^{-1}\), the ambient temperature is within the range of \(-10^\circ\text{C}\) to \(45^\circ\text{C}\), and the relative humidity is less than 85\%. The time interval between each vehicle passing should be greater than 1 s.

2.2. Data treatment

Exhaust emissions from motor vehicles into the air will immediately diffuse and cause the concentration of pollutants to decrease. However, the absolute concentration of the exhaust gas in the initial stage of diffusion (within one second) remains unchanged. Thus, the concentration of each pollutant in the exhaust gas can be calculated using the combustion equation \([10\text{--}12]\). In remote sensing test, the relative concentration of pollutants over carbon dioxide was monitored. The reference gas is CO\(_2\). The ratio of CO, HC, NO to CO\(_2\) concentration in the exhaust were \(Q_{\text{CO}}\), \(Q_{\text{HC}}\), and \(Q_{\text{NO}}\) which \(Q_{\text{CO}} = \text{CO}/\text{CO}_2\), \(Q_{\text{HC}} = \text{HC}/\text{CO}_2\), \(Q_{\text{NO}} = \text{NO}/\text{CO}_2\). Based on the combustion equation theory, the pollutant concentration in the exhaust can be got by measuring the mutual proportion of pollutants. Finally, these remote sensing data are converted into emission factors of pollution (g/kg\(^*\) fuel).

\[
E_{\text{CO}} = \frac{2000 \times Q_{\text{CO}}}{1 + Q_{\text{CO}} + 6Q_{\text{HC}}}
\]

\[
E_{\text{HC}} = \frac{6285 \times Q_{\text{HC}}}{1 + Q_{\text{CO}} + 6Q_{\text{HC}}}
\]

\[
E_{\text{NO}} = \frac{2143 \times Q_{\text{NO}}}{1 + Q_{\text{CO}} + 6Q_{\text{HC}}}
\]
2.3. Quality assurance and quality control
The principle of Vehicle exhaust remote sensing test system is non-contact measurement. The optical path of the remote sensing test equipment is open. The installation and use environment of exhaust remote sensing test equipment is on the roadside. The measurement process is easily affected by ambient temperature, humidity, wind, vehicle speed, and the background value of the previous vehicle. To ensure that the remote sensing test results can more accurately reflect the really emission level, the installation and use of remote sensing test equipment and data processing require related quality assurance and quality control procedures. (Details are in the supplementary materials (available online at stacks.iop.org/ERC/4/055008/medial))

3. Results and discussion
3.1. Vehicle fleet characteristics
In this study, the remote sensing test data of Tianjin in 2018 and 2019 were selected. During the measurement period, the remote sensing test system tested 418900 local vehicle times that contained valid information of 179589 duplicate vehicle records. We screened the remote sensing test data for duplicate vehicles in 2018 and 2019 (table 1). Relatively stable vehicle type and distribution characteristics can be used to verify impact of ethanol-gasoline implementation on vehicle emission.

According to the vehicle type classification method in Chinese standards, the test vehicles are divided into mini vehicle, small vehicle, medium vehicle, large vehicle. The small passenger cars accounted for the largest proportion. Table 1 shows the sampled repeat fleet characteristics by vehicle emission standard and vehicle type. To ensure statistical validity of EFs for survey and assessment, there is a minimum of 100 records used for each vehicle type and emission standard [13, 14]. The gasoline vehicles tested by remote sensing were mainly small passenger cars and light trucks, and the number of tested vehicles was 172263 and 7336, respectively. Among the
small passenger cars and light trucks, the China III, China IV and China V emission vehicles are the main vehicle emission standards. The test number of other types vehicles is less than 100. Therefore, this study conducts an in-depth analysis of small passenger cars and light trucks.

3.2. Emission characteristics before and after ethanol-gasoline implementation

In this study, the HC-CO-NO emission factors are in grams per kg of fuel consumed (g/kg fuel). Figures 2 and 3 show the mean emission factors of HC-CO-NO of different vehicle type and emission standard. The vehicles are categorized into two groups by the vehicle type of small passenger cars and light trucks. As shown in figure 2, the average emission concentration obtained through remote sensing tests showed a continuous downward trend after ethanol-gasoline implementation (2%–9%). The three pollutant emission factors of small passenger cars are all lower than those of light trucks. Overall, the HC-CO-NO emission factors obtained through remote sensing tests have a tiny range of variation. This is mainly because gasoline vehicle exhaust gas after-treatment equipment has not undergone major changes, and three-way catalytic converters have been used as after-treatment equipment. With the implementation of yellow label vehicles elimination and old vehicles elimination, in use gasoline vehicles are basically China III–V emission standards (figure 3).

Figure 4. Mean HC–CO–NO emission factors of each decile for different test year.
| Research source | Test time | Vehicle number | Method | CO | NOx | HC |
|-----------------|-----------|----------------|--------|----|-----|----|
| [18]            | 2012      | 7              | DET    | Mostly decreased | Mixed results | Decrease |
| [19]            | 2009      | 16             | DET    | Decreased 10%–15% | No trend | Mixed results |
| [20]            | 2017      | 1              | DET    | Decreased | Mixed results | Increased up to 162% |
| [21]            | 2012      | 1              | DET    | — | Decreased 10%–20% | Decreased 10%–20% |
| [22]            | 2014      | 3              | PEMS   | Mixed results | Decreased 40%–45% | Decreased 30%–47% |
| [23]            | 2018      | 1              | DET    | Decreased 20%–35% | Decreased 17%–36% | Decreased 9%–13% |
| this study      | 2018 & 2019 | 179589       | RST    | Decreased 2%–9% | Mixed results | Decreased 3%–8% |

DET: Dynamometer Emission Test.
PEMS: Portable Emission Measurement System.
RSD: Remote Sensing Test.
All emissions are arranged in ascending order and divided into ten groups with equal distance (deciles). Figure 4 shows the mean emission factors of HC–CO–NO in each decile for different test year. The distributions of HC–CO–NO emission factors are highly skewed. The 2nd to 9th deciles of emission level show fluctuates slightly, which indicate that high-emission vehicles are basically distributed in the 10th stage. The emission factor of 10% high-emission vehicles is several times that of other groups of vehicles. From the results of the two-year test data, the emission levels of the 10% worst emission vehicles have shown a certain reduction compared with before the ethanol-gasoline implementation. This may be due to various reasons. Firstly, some high-emission vehicles have been repaired and the pollutant emissions reduced. Secondly, with the ethanol-gasoline implementation, fuel changes will bring about changes of pollutant emissions. Generally, CO and HC are the products of incomplete combustion of fuel in gasoline engines [15]. Due to the chemical composition of ethanol, such as low carbon content, high oxygen content, low carbon/hydrogen ratio, the addition of ethanol can ensure that the fuel burns more completely. Because of the high latent heat vaporization of ethanol-gasoline, the temperature of the mixed gas will decrease [15]. Ethanol-gasoline can significantly reduce combustion and emission temperatures, thereby reducing NO emissions [16]. However, the rich oxygen in ethanol fuel may cause additional formation of nitrogen oxides. At the same time, ethanol fuel has little change in the excess air coefficient in the system, and the free oxygen ions are not conducive to the reduction of NO in the three-way catalyst, resulting in a slight decrease in the conversion efficiency of NO [17].

3.3. Compared with other studies

In previous studies to test the effects of ethanol-gasoline emissions, the methods of chassis dynamometer testing and on-board testing were used. Ethanol fuel has different trends in the decrease/increase of different pollutants. Totally, there is a decreasing trend for carbon-containing pollutants (CO and HC). However, due to the poor performance of ethanol-gasoline in terms of fuel consumption, NO emissions generally show an increasing trend. As shown in table 2, the test vehicle number in the dynamometer emission test and on-board test is often only a few and no more than 20. With such a few test samples, the uncertainty of the measurement results is very large. In order to solve this problem of greater uncertainty, we pioneered to use big data of vehicle remote sensing test for analysis. Remote sensing test big data has certain advantages that can reduce random errors. Statistical results based on large sample size data are more accurate. However, the remote sensing test is aimed at the instantaneous emission characteristics of vehicles under specific operating conditions on road. The operating conditions of the remote sensing test are relatively single and cannot fully cover the various operating conditions of vehicles. Secondly, the part of evaporative emissions has not been quantified. In the future, it is necessary to strengthen in-depth research and analysis in the field of ethanol-gasoline emissions from motor vehicles.

4. Conclusion

This work is aiming to investigate gasoline vehicle emissions for two distinct periods: before and after the ethanol-gasoline implementation. Remote sensing technology was used to measure the on-road vehicle emissions in 2018 and 2019. During the test, the 418900 records were obtained, which contained valid information of 179589 duplicate vehicle records with matched vehicle plate information.

The average emission concentration obtained through remote sensing tests showed a continuous downward trend after ethanol-gasoline implementation (2%–9%). The HC–CO–NO emission factors of small passenger cars are all lower than those of light trucks. Overall, the HC–CO–NO emission factors obtained through remote sensing tests have a tiny range of variation, because of three-way catalytic converters have been used as after-treatment equipment.

For deciles of emission, the distributions of HC–CO–NO emission factors are highly skewed. The high-emission vehicles are basically distributed in the 10th stage. From the results of the two-year test data, the emission levels of the 10% worst emission vehicles have shown a certain reduction compared with before the ethanol-gasoline implementation. Some high-emission vehicles repaired and the ethanol-gasoline implementation can bring about changes of pollutant emissions.

Compared with other studies via the dynamometer emission test and on-board test, the remote sensing test big data has certain advantages that can reduce random errors. Statistical results based on large sample size data are more accurate. However, the remote sensing test can only obtain the vehicle emission characteristics under specific operating conditions, which cannot fully cover the vehicle operating conditions. The evaporative emissions of vehicle cannot be quantified by the remote sensing test. In the future, it is necessary to use a variety of vehicle exhaust detection methods to determine the emission impact of ethanol-gasoline implementation to more accurately.
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Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

Author contributions

Qijun Zhang: Conceptualization, Methodology, Investigation, Writing-Original draft preparation, Writing-Reviewing and Editing. Ning Wei: Data curation, Software. Hongjun Mao: Funding acquisition, Methodology, Writing-Reviewing and Editing.

Competing interest statement

The authors declare no competing interest.

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