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Remote Sensing Measurement and Analysis for Alcohol-gasoline Vehicle

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Abstract: Alcohol-gasoline blends vehicles was used to determine the on- road motor vehicle emissions for the real urban driving cycles by using remote sensing measurement technique. Based on the measured emission data the CO, HC and NOx emissions of the whole fleet in Haerbin are contributed by 37, 53 and 45% high emitting vehicles. Simultaneity, lower vehicle speed, higher load and useful frequency result higher emission factor of automobile.

Key words: Vehicle emission,remote sensing measurement, emission factor, alcohol-gasoline

INTRODUCTION

Since the 1980s, the progress of urbanization in our country has been accelerating. Up to now, the percentage of urbanization has increased from 26% in last 90s to about 48%. In the process of rapid urbanization, the problem regarding the over consumption of petroleum has become more and more serious. At present, the quantity of automotive vehicle in our country has approached 200 million (by the end of 2010). The over consumption of petroleum and the environmental pollution caused by the combustion of oil have attracted extensive attentions. Therefore, a lot of methods have been put forward to decreases in mainly CO, HC and Nox emissions (Ruan *et al.*, 2012; Cheng *et al.*, 2012) and the usage of alternative fuel is one of the effective methods.

Ethanol gasoline fuel, one kind of alternative clean fuels for motor vehicles, is prepared by fixed ratio of ethanol (C_2H_6O) and gasoline. This fuel has many notable advantages, such as high octane number, good antiknock property and so on. In Heilongjiang, Jilin and Henan provinces, this fuel has been widely used now. However, the compare of actual pollutants produced by vehicles using ethanol gasoline fuel and using petroleum has not been reported before. In this study, the remote sensing technology has been applied to test and analyze the real-time actual discharge of vehicles which consume the ethanol gasoline fuel on the roads in Harbin. These acquired data are useful for mastering the law of vehicles' emission in this area and analyzing the factors which affect emission.

REMOTE SENSING EXPERIMENT

Data acquisition and principle of sensing: In this study, RSD3000 remote sensing system supplied by American

Fig. 1: Schematic diagram showing the remote-sensing on road

ESP Company had been implemented to acquire the data. The system was composed of light generator, detector, laser speed measuring equipment, camera, data processing system, monitor and so on. The system sensed the vehicle emission (CO_2, CO and HC were detected by infrared rays and NO_x was detected by ultraviolet rays) through pollutants absorbed light wave with different frequencies at different degrees. During the process of sensing, infrared and ultraviolet beams (IR/UV) moved horizontally across the road. The light beam went across the emitted exhaust by the exhaust pipe of the motor vehicle when the motor vehicle was driven on the road. Then, a part of the beam was absorbed and the signal of light intensity was changed. The amount of pollutants discharged by the motor vehicle in actual driving condition should be monitored by the non-contact measurement. The principles of sensing were shown in Fig. 1.

The data of remote sensing were monitored in the actual traffic circumstance in the city of Harbin from April 2011 to April 2012. The monitoring sites were set in the

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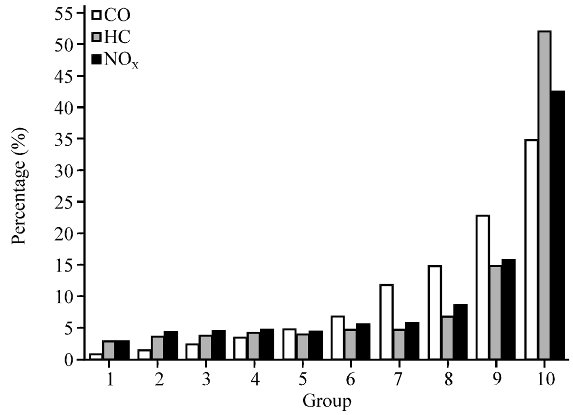

Fig. 2: CO, HC and NOx deciles distribution for remote sensing data

typical roads (considering slope) and traffic circumstance (considering traffic flow, average speed and accelerated speed) in the city. The characteristics of monitoring sites were shown in Fig 1. In order to avoid the influence of environmental factors, the tests were performed under a suitable condition that the velocity of air near the ground should be lower than 0.5 m sec^{-1}, the temperature should be 15±5°C and the humidity should be 50±5%. The total number of collected samples was 12057 and there were 8537 effective results. The information of each effective sample should include the concentration of CO_2, CO, HC and NO_x, speed and accelerated speed of a motor vehicle, mileage, date of manufacture, relevant activities for reducing exhaust and so on.

Results and analysis: To analyze the concentration distribution and evaluation of contribution of CO, HC and NO_x discharged by vehicles use ethanol gasoline fuel efficiently, all of the monitoring vehicles were divided into 10 groups. Each group should have the same number of vehicles and the rule of division was based on the gradually increased concentration of discharged gas. The concentration distribution monitored and evaluation of contribution of CO, HC and NO_x discharged by vehicles use ethanol gasoline fuel were showed in Fig. 2. It showed that a large proportion of the vehicles not only produce lower concentration of discharged gas but also contribute less to the total emissions. In addition, the percentage of high discharged vehicles was 10%. The contributions of CO, HC and NO_x to total pollution should be 37, 53 and nearly 45%, respectively.

Moreover, the determined results were compared with other cities, as shown in Table 2. The contributions of high discharged vehicles in different cities had similar phenomena. The contributions of discharged CO and HC in Harbin were lower than Hongkong and Taiwan but slightly higher than Hangzhou. Compared with the developed areas, the high polluted vehicles were relatively common. Therefore, generally speaking, the proportion of the high polluted vehicles in Harbin was less than Hong Kong and Taiwan.

Table 1: Characterization of the measurement sites

Type of street	Test time (month)	Traffic flow (No. h^{-1})	Slope of road (°C)	Average speed (km h^{-1})	Averagespeed (km h sec^{-1})
Site 1	4-Jan	384-465	1.9	10.5-88.2	-3.77
Site 2	4-Jan	1101-1431	1.7	9.8-86.4	-3.91
Site 3	4-Jan	647-745	0.2	9.6-93.5	-3.26
Site 4	4-Jan	263-767	1.0	17.2-66.4	-3.95
Site 5	4-Jan	582-731	0.0	18.3-70.5	-3.69

Table 2: Contribution from high-emitting vehicles (top 10% of emitters) in different cities

Region	CO (%)	HC (%)	Nox (%)
Harbin	39	46	65
Hangzhou (Lau *et al*., 2012)	35	45	50
Hongkong	59	47	56
Taiwan	60	45	40

CALCULATE AND ANALYZE THE EMISSION FACTORS OF ETHANOL GASOLINE FUEL

Calculation of emission factors: According to the actual monitoring data of remote sensing, the carbon in the ethanol gasoline fuel was discharged as CO, CO_2 and HC. Therefore, the emission factors were able to be calculated through the discharged concentration of CO, HC and NO_x. The formulas of calculation were shown as below (Guo *et al*., 2007):

$$EF_{co} = \frac{C_{co}}{C_{co_2} + C_{co} + 4C_{HC}} w_c \rho_f \frac{M_{co}}{12} \quad (1)$$

$$EF_{HC} = \frac{C_{HC}}{C_{co_2} + C_{co} + 4C_{HC}} w_c \rho_f \frac{M_{HC}}{12} \quad (2)$$

$$EF_{NO_x} = \frac{C_{NO_x}}{C_{co_2} + C_{co} + 4C_{HC}} w_c \rho_f \frac{M_{NO_x}}{12} \quad (3)$$

C_{co_2}, C_{co}, C_{HC} and C_{NO_x} were the concentration of CO_2, CO HC and NO_x, respectively. ρ_f was the average density of ethanol gasoline fuel. M_{co}, M_{HC} and M_{NO_x} were the molar weight of CO, HC and NO_x, respectively. The percentage of carbon in the fuel was shown as w_c. EF_{co}, EF_{HC} and EF_{NO_x} indicated the emission factors of CO, HC and NO_x. In the course of remote sensing, the concentration of HC was measured by non-dispersive infrared. Compared with standard hydrogen-flame ionization determination, the measured data of alkenes,

Table 3: Emission factors in different cities

Region	No. of tested vehicles	CO (g L^{-1})	HC (g L^{-1})	Nox (g L^{-1})
Harbin	8537	164.05	18.65	5.04
Hangzhou	32260	193.07±15.63	7.75±1.95	3.68±0.31
Hongkong	8544	36.3	5.18	3.7

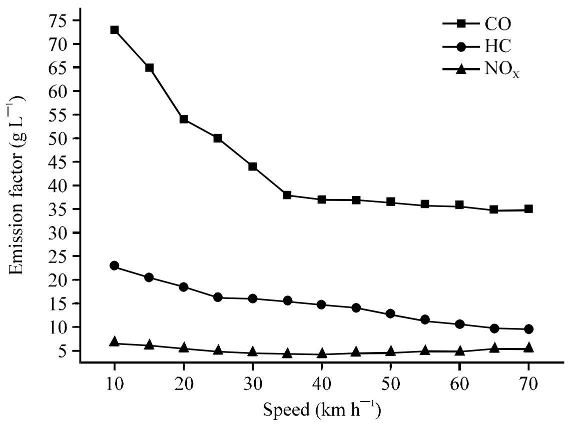

Fig. 3: Variations of emissions with the different vehicle speed

alkynes and aromatic were less reliable. Based on the previous conclusions through the research in tunnel, the relevant coefficient of HC was set as 3.6.

Generally speaking, the level of discharged CO reflected the overall discharged level of specific area (Guo *et al*., 2007). As shown in Table 3, the discharged level of motor vehicles in Harbin was nearly the same with other cities in China. The emission factor of CO in Harbin was about 80-90% of Hangzhou and 4 times of Hongkong. Also, the emission factor of HC in Harin was 1.92-3.21 times of Hangzhou and 3.6 times of Hong Kong. The possible main reason for relative higher emission factor of NO_x in Harbin was that the engines always worked with lower air fuel ratio due to the frequently modified speed of vehicles in the process of running. Besides (Lau *et al*., 2012), the oxygen was rich in gasoline and the engines were in the state of oxygen-enriched combustion. Oxygen-enriched combustion contributed to the generation of NO_x and reduction of discharged CO. The relatively poor traffic environment and not timely repair of vehicles were the main reasons for the relatively higher discharged NO_x in Harbin.

Effect on emission factor by the speed of motor vehicles: As shown in Fig. 3, the emission factor of CO in ethanol gasoline fuel changed with the change of instantaneous speed and the tendency seemed like "L". Along with the increasing speed, the emission factor reduced quickly at first and then decreased slowly. The rotation rate of engines was slow with the slow speed of vehicles. Then,

Table 4: Emission factors in different vehicle types

Types of vehicles	CO (g L^{-1})	Nox (g L^{-1})	HC (g L^{-1})
Light weight car	85.7	4.8	12.4
Taxi	73.3	5.9	24.5
Small passenger car	75.6	6.5	24.6
motorcycle	61.4	4.3	13.5

the flow of air was slow and the mixed air was not uniform. In order to ensure the stable operation of the engine, the mixed gas was required to achieve more concentrated state. Therefore, the instantaneous discharging rate was relatively higher. When the vehicles ran at high speed, the combustion was more sufficient. In addition, the mileage was so long that emission factor of CO decreased with the enhanced averaged speed.

The red curve in Fig. 3 indicated the emission factor of HC of ethanol gasoline fuel. When the speed of vehicles was in the range of 10-75 km h^{-1}, the emission factor of HC decreased with the increased instantaneous speed. At the beginning, the incomplete combustion that caused by uniformly mixed gas and low working temperature in the cylinder led to the high emission factor.

The emission factor of NO_x was also shown in Fig. 3 (blue line). When the vehicles had the running speed from 20 to 40 km h^{-1}, the emission factor of NO_x was relatively higher and decreased slowly along with the increased instantaneous speed. However, the emission factor of NO_x increased with the increasing instantaneous speed if the running exceeded 40 km h^{-1}. The slow running speed contributed to the short mileage and high emission factor of NO_x. In the process of increasing speed, the output power of engine would gradually increase. Not only the consumption of fuel became more and more but also the press and temperature of combustion increased gradually. All of these factors had greatly promoted the generation of NO_x and the overall emission of NO_x increased.

Effect on the emission factor by different types of vehicles: As shown in Table 4, for different pollutants, different types of vehicles had great differences. Among all of the ethanol gasoline vehicles, car had the highest emission factor of CO. Small passenger car had the highest emission factor of NO_x and HC and taxi ranked second. Due to the limited urban traffic conditions, cars had low running speed in a long term and the discharged CO was high. Compared to other vehicles, small passenger car had relatively higher load which was decided by transport of goods and passengers. Hence, the emission factors of NO_x and HC were high. This conclusion also confirmed that the discharged of NO_x and HC were proportional to vehicles load as previous study (Pokharel *et al*., 2002). As a result of frequently usage and higher mileage, the engine of cars and some purified

Table 5: Comparison of emission factors for different year

	Ethanol gasoline fuel			Liquefied petroleum gas (LPG)		
Year	CO ($g\ L^{-1}$)	HC ($g\ L^{-1}$)	Nox ($g\ L^{-1}$)	CO ($g\ L^{-1}$)	HC ($g\ L^{-1}$)	NOx ($g\ L^{-1}$)
2006	243.2	. 141	13.2	250.1	18.6	24.7
2008	183.4	13.1	6.8	200.6	20.8	9.4
2012	85.7	12.4	4.8	98.5	24.5	6.4

technologies such as three element catalytic purification tended to worsen. Moreover, Lack of routine maintenance, the emission of cars was relatively poor. Therefore, in order to achieve the purpose of environmental purification, different purified technologies aimed to different key points should be employed to keep different types of vehicles in good repair.

Effect on the emission factor by emission standards: To evaluate the relationships between vehicle emission and emission standards, the emission factors of vehicles of Harbin in 2006, 2008 and 2012 were compared. Table 5 showed that emission factors of CO, NO_x and HC in 2012 were less than in 2006 and 2008. To meet the national mandatory emission standards, the discharged technologies of new cars such as using new energy were strengthened. The similar conclusion was also shown in the literature (Kuhns *et al*., 2004). Furthermore, the emission factors of vehicles with ethanol gasoline fuel were lower than the vehicles with Liquefied Petroleum Gas (LPG) as a whole. By comparison with small cars which mainly consumed ethanol gasoline fuel, public transportation vehicles that mainly consumed the new energy LPG had more frequently parking and starting and were usually in the state of overload and low running speed. The emission factors of LPG were accordingly relatively higher.

ACCURACY'S ANALYSIS OF REMOTE SENSING MONITORING DATA

Based on the emission concentration and factors, to test the accuracy of remote sensing monitoring data regarding the vehicles that consumed ethanol, the existing mature monitoring method or model were compared and the errors were analyzed.

Comparison between remote sensing monitoring and idle state method test: The idle state method test was a typical testing method that tests the exhaust emission of spark ignition engine. In this study, AUTO5-1 motor vehicle exhaust gas analyzer was employed to detect the exhaust emission in the exhaust pipe of vehicles. The comparison of the same vehicle between remote sensing monitoring value (x) and idle value (y) were completed. The

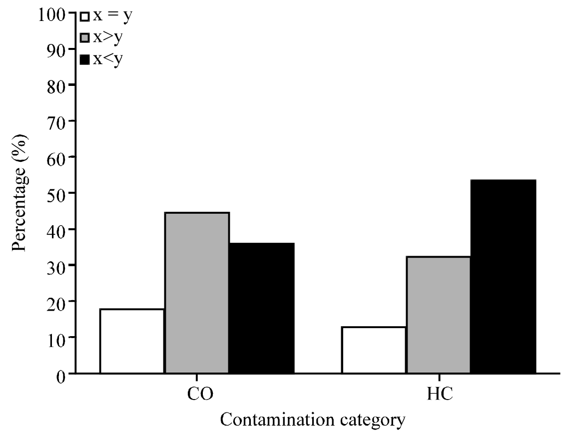

Fig. 4: Comparison of value to idle measurements and remote sensing measurements

calculation of the number of vehicles corresponding to each type was shown as more than, equal to and less than. Meanwhile the number's percentages of various types of vehicle were drawn as bar chart. All of these data were shown in Fig. 4. In Fig. 4, it was found that remote sensing HC of most vehicles was less than the idle value, but the sensing CO was higher.

Generally speaking, in a certain range of engine's speed, the discharged concentration of HC changed a little with the increase of rotation rate. However, the discharged concentration of CO decreased obviously along with the increase of rotation rate. In the actual detective process, the detection usually took place until the engine is medium load when the remote sensing method was applied. However, in the process of idle state test, the detection took place when the engine had no load and the rotation speed was high. According to analysis of engine load, the discharged concentrations of HC and CO that detected by remote sensing monitoring method were lower than by idle state method test. Based on the analysis of rotation rate, the detected concentration of HC should be the whole as same as each other. The detected concentration of CO that detected by remote sensing monitoring method should be higher than by idle state method test. By comprehensive analysis, the detected HC of most vehicles that obtained by remote sensing monitoring method test should be less than the value detected by idle state method. The detected CO that obtained by riddle state method should be less than the value detected by remote sensing method. All of these conclusions were in accordance with actual test results.

Comparison of emission factors between remote sensing monitoring and IVE model: IVE model that developed by California university of United states was designed for

Table 6: Comparison of emission factors to IVE model and remote sensing measurements

Types of pollutants	Engine displacement	IVE (g L^{-1})	Value of remote sensing monitoring (g L^{-1})
CO	<1.5L	64.87	76.30
	1.5-2.0L	70.64	79.10
	>2.0L	71.45	75.80
	<1.5L	27.51	27.50
HC		28.67	28.12
		24.06	24.37
	<1.5L	12.90	5.86
NOx	1.5-2.0L	23.60	4.62
	>2.0L	25.84	5.26

developing countries to predict the exhaust emission of vehicles. Through establishing the relationships between the exhaust emission and the accelerated speed, this model was able to reflect the exhaust emission of vehicles in actual roads. In this study, the data predicted by IVE model was compared with the data acquired by remote sensing monitoring. As shown in Table 6, the emission factors of HC predicted by IVE model were consistent with the data detected by remote sensing monitoring. For the emission factor of CO, data predicted by IVE model was lower than the one obtained by remote sensing. For the emission factor of NO_x, predictive data were higher than detected. The differences of emission factors between IVE model and remote sensing monitoring method had certain reasons which mainly included several aspects as follows. First of all, in order to unify the testing conditions, the data used for prediction of IVE model were acquired by remote sensing monitoring. These parameters included the average speed, VSP, I/M standard, fuel type, environmental parameters (temperature, humidity) and so on. Although the purpose of developing this model aimed to realize the localization in developing countries, the database of IVE emission model was established through the FTP cycles of United States. There should be some difference between practical application in this study and the model, such as the specific maintenance of vehicles, actual traffic conditions, etc. The calculated deviations caused by these differences were also discussed in the literature. Therefore, it could be inferred that the effective combination of above-mentioned two methods should have greatly improved the predictive accuracy of the emission model of local vehicles.

Secondly, the combustion condition of engine may be one reason for certain differences of emission factors between IVE model and remote sensing monitoring method. Generally speaking, the power of vehicles that used ethanol gasoline fuel was lower than the ones used pure gasoline. In the course of driving, the drivers usually made the engine work in the state named “oil-rich” for a long time (Liu *et al*., 2012). Then, the air-fuel ratio of combustion was too small, the emission of NO_x became less and the emission of CO increased. In IVE emission model, the reason that driving causes influenced the air-fuel ratio had never been taken into the account.

CONCLUSION

In this study, the emissions of CO, HC and NO_x exhausted by the vehicles with ethanol gasoline fuel under actual running conditions in Harbin were effectively monitored through remote sensing monitoring method. The monitored results were shown as below:

- The average emission of vehicles in Harbin was behind some developed areas and still high. The high-polluting vehicles were relatively common. It was very important to control these vehicles that included the old vehicles and the vehicles with relatively backward emission technologies
- The emission of CO, HC and NO_X in ethanol gasoline fuel vehicles were significantly affected by the running speed. The emission factors of CO, HC and NO_x were relatively higher when the running speed was low. The emission factors decreased with the increasing average speed. Therefore, in order to reduce the emission of vehicles, optimization of traffic, reduction of congestion and improvement of speed had great significance
- The emission factors of pollutants were also greatly influenced by different types of vehicles. Cars had higher emission factor of CO than other vehicles. The vehicles that had bigger carrying capacity and longer mileage had higher emission factors of HC and NO_x. Hence, in order to achieve the purpose of environmental purification, it is necessary to strengthen different purified technologies for different types of vehicles

According to the comparison between the idle state method and the IVE emission model, it could be found that the remote sensing method have the ability to monitor the pollutants’ concentration of vehicles more accurately. The remote sensing monitoring method was able to provide strong technical support to construct the emission inventory of urban vehicles.

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