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A remote sensing system of vehicle emissions based on tunable diode laser technology

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Abstract: As being an effective real-time method of monitoring vehicle emissions on-road, a remote sensing system based on the tunable diode laser (TDL) technology was presented, and the key technologies were discussed. A field test in Guangzhou(Guangdong, China) was performed and was found that the factors, such as slope, instantaneous speed and acceleration, had significant influence on the detectable rate of the system. Based on the results, the proposal choice of testing site was presented.
Keywords: remote sensing; tunable diode laser; vehicle emission; detectable rate

Introduction

Vehicle emissions are the major source of air pollution in most urban cities. Carbon monoxide(CO), carbon dioxide(CO_2), hydrocarbons(HC) and nitrogen oxides (NOx) are the major pollutants from vehicle exhaust. They are harmful to health and enviormnent, leading to the greenhouse effect and engender photochemical smog. According to worldwide reports, vehicle emissions contribute over 60% of the CO, over 20% of the NOx and over 30% of the HC to the national emission inventory (USEPA, 1998; Pokharel *et al.*, 2001a, 2003). For the protection of the atmosphere, the accurate measurement of the exhausts is becoming more and more important.

The two traditional ways of measuring vehicle emissions are idle and dynamometer testing, both of which have many shortcomings. Idle testing is not representative of real emissions and dynamometer testing requires large amount of resources and still marginally represents of real emissions. Remote sensing of vehicle emission was developed as an alternative to them. Being an effective real-time method of monitoring vehicle emissions under normal driving operations, great attention has been paid to the remote sensing technology of vehicle emissions in recent years. Non-dispersive infrared (NDIR) instruments to measure the CO emissions and HC emissions were pioneered by the University of Denver in the late 1980s (Bishop *et al.*, 1989). But successful remote sensing measurement of exhaust NOx has been more difficult. Nelson reported a TDL system for the remote sensing of on-road vehicle emissions in 1998 (Nelson *et al.*, 1998). Now, that remote sensing vehicle emissions system has been widely used in the United States, Canada, Mexico, Australia and so on (Chan *et al.*, 2002).

Since the system has not been applied widely and effectively in China, this paper looks at its application in China and analyzes the key technique of the system based on a detailed introduction to a remote sensing system of on-road vehicle emissions using TDL technology.

1 Basic theory of TDL technology

Remote sensing is an extension of a standard laboratory analytical technique called long paths photometry. There are many ways to measure exhausts from vehicle on-road, such as NDIR, fourier transform infrared (FTIR) instruments. However, the sensitivity, the pollutants measured and the operational range are limited in these technologies, especially for the measurement of NOx. For these reasons, considerable effort has been done to develop new measurement techniques. A TDL system was applied to remote sensing (Nelson *et al.*, 1998) which showed great advantages. Compared to NDIR instruments, the TDL technique has a significant increase in sensitivity up to 100 times for the measurement of some molecules and has greater operational range (Jimenez *et al*, 1999). TDLs are small crystals of Ga, As, Sb, and P, similar to the lasers used in the telecommunications, CD players and laser printers. TDLs are superior for measuring a wide range of concentrations. When an electrical current is supplied, TDL lasers emit known ranges of radiation. In fact, the wavelength of emitted radiation can be changed within a narrow range by varying the current applied to the crystal. Because the absorption line of each pollutant is known, different wavelengths are emitted by the lasers to detect different pollutants. Besides the great characteristic of laser, such as mono-chromaticity, directivity and

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high-intensity, each emitted wavelength is very precise, and when an interference-free absorption line is chosen, it is not affected by particulate matter or other gases in the exhausts.

TDL technology meets the standard and requirements of remote sensing which the previous techniques could not achieve.

2 System description

2.1 System composition

The system is composed of five parts: the vehicle emission analyzer subsystem, the license plate recorder, the speed and acceleration measurement subsystem, and the local database management, in addition, the data communication subsystem and the vehicle database management system was located in the Environment Protection Agency (EPA). Fig.1 shows the frame of the system.

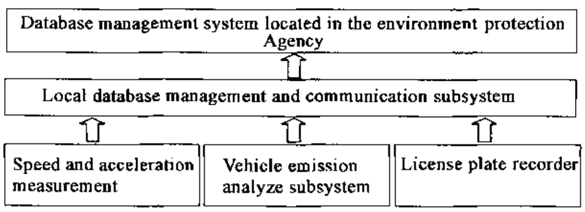

Fig.1 Frame of remote sensing system of vehicle emission

When a moving vehicle passes the measurement system, its speed and acceleration are first measured to determine the vehicle engines character to reduce the error produced in abnormal states. At the same time, emission measurement instrument waits for vehicle to block the bean and collect a background measurement. Then, sending laser sensing beams across the road through the exhaust plumes of the passing vehicle, the vehicle emission analyzer subsystem analyzes the concentration of the pollutants by changing the intensity of the beams. The license plate recorder is used to identify the vehicle, then, the data on the detected vehicle can be obtained in detail. Finally, all the messages are sent to the database management subsystem in the EPA.

2.2 Key technologies

The system measures vehicle emissions as the vehicle passes in real time. Fig.2 presents the working process.

Due to the need for accuracy and rapid response, it is important to consider the factors that affect vehicle emissions as these will also affect the measurement system. They are testing site, vehicle type and maintenance, vehicle power demand, fuel type operating model and random fluctuations(Sadler *et al.*, 1996) and the dispersion pattern.

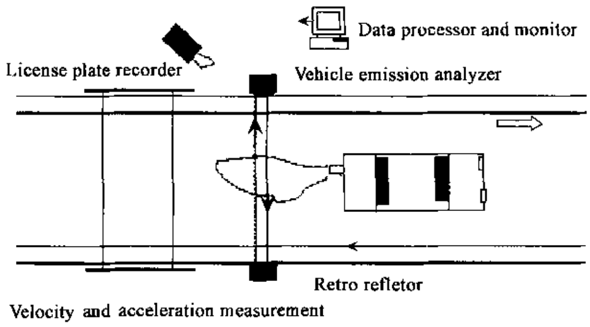

Fig.2 Remote sensing system of vehicle emission based on TDL

TDL technology detects the concentration of each pollutant by identifying the absorption peaks of the pollutants. It is important to choose an interference-free absorption band as each molecular composition has its own characteristic wavelength. According to the HITRAN data-base (Harvard University), they are 2000 nm for CO_2, 1570 nm for CO, 1650 nm for HC and 670 nm for NOx. As an example, Fig.3 shows the absorption line of CO_2.

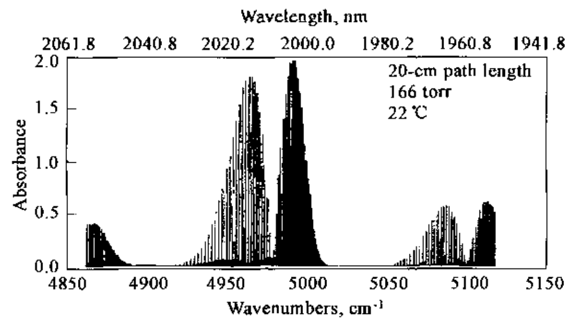

Fig.3 The absorption line of CO_2

Another important factor is the dispersion of the pollutants after being exhausted from the vehicle plumes. The classical method uses CO_2 as the referenced gas which allows one to make quantitative measurements of other pollutants without knowledge of the exhaust plume location or the extent of dilution, since Bishop proved that the ratio of the volume emission concentration along the vehicle exhaust plumes does not change during the remote sensing measurement (Pokharel *et al.*, 2001b). And the complete combustion of a fuel produces a known CO_2 concentration.

The appropriate choice of the detecting site can reduce the influence of the operation model. Road grade must be an important effect to consider. Generally, the best site is where the vehicle fleet is flowing smoothly, with an average flow of vehicles from 200 vehicles/h to 360 vehicles/h (Stedman and Bishop, 1990) and average speed from 10 km/h to 110 km/h, such as it is found on motor way off-ramps.

Besides these factors, stability, noise inhibition, thunderstorm protection, other types of uncertainty (systematic bias, instrument drift etc.) and point of interruption in the communication should be taken into account.

Table 1 shows the detecting index of the system, when it works at mal-condition.

Table 1 Main technology index

The accuracy of CO testing	± 0.25 of concentration or 10% for measurement
The accuracy of NOx testing	±250 ppm or 15% for measurement
The accuracy of HC testing	±250 ppm or 15% for measurement
The accuracy of speed measurement	±0.1 miles/h
The accuracy of acceleration measurement	±0.5 miles/h

3 Application

3.1 Experiment in Guangzhou (Guangdong Province, China)

The measurement was performed in Guangzhou, China. Owing to the effects mentioned before, four different roads were selected to ensure a good representation of data. 11028 groups of data with 7683 valid were obtained. Experimental valid data refer to these data which include five valid parameters (i.e. vehicle instantaneous speed, acceleration, the emissions of CO, HC and NOx). The detectable rate (the ratio of the valid measurement data) in the primary study is higher than 68% which was published in the study of the infrared remote sensing of on-road vehicle emissions in Washington State(Kerry, 1999).

The primary study was focused on the relationship between the detectable rate and the influential factors, such as road grade, vehicle speed and acceleration. As Peter McClintock studied, the load contributed by the slope of the site comes from acceleration against the Earth's gravitational force, and a 5% grade is equivalent to a horizontal acceleration of 1.9 mph/s (McClintock, 2002). That is to say, the study was emphasized on the effect of operating condition. Fig.4 shows the different effects of the different influential factors in detectable rate, and three elemental conclusions are obtained. First, the road grade has a little influence on detectable rate. The 3.5° reached the best rate, so a moderate upward slope will have advantage in remote sensing. Second, acceleration has a great effect on detectable rate. With the increase of acceleration, the general trend of detectable rate is increasing. Third, when speed varied at the range from 20 to 50 km/h, the detectable rate is stable and high, exceeding 75% . Under these conditions, the states of vehicle(i.e. relatively speed, a little accelerating and climbing) ensured the largest emission plume, so the highest detectable rate in this experiment was achieved. From the experimental data, in order to ensure the maximum number of valid emission readings, the recommendable choice of site is that the range of speed is from 15 to 75 km/h, the range of acceleration is from 0 to 1.6 m/ (h·s) and the range of road grade is from 0° to 5°.

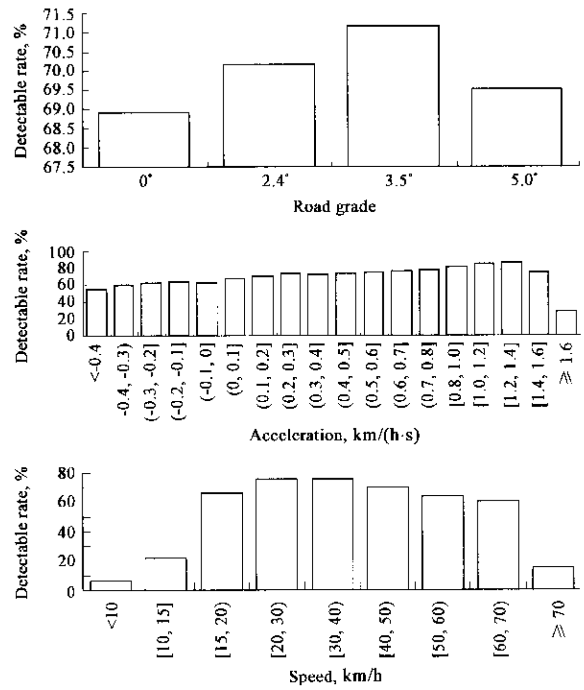

Fig.4 Effect of different influencing factors in detectable rate

3.2 Advantages at application

The system based on TDL technology is one of the most advanced approaches to measure emissions remotely. Compared to traditional ways, it is easy to set up, has low cost, and needs no operator. Since 10% of vehicles contributes 50% of the pollution(Bishop *et al.*, 1996), the system is the most effective way to identify excessively polluting vehicles. Having no operator on the detection spot and doing remote diagnosis and maintenance not only reduces the inconvenience for the tester and drivers but also avoids corrupt transactions between the tester and drivers. What is more, according to a research from Denver University, remote sensing correlated very well with IM240 (the most advanced dynamometer testing nowadays which was originally designed to be 240 s), data averaged(g/kg fuel), R^2 is 0.9736 for CO detection, 0.9783 for HC, and 0.9783 for NOx detection. In addition the cost of IM240 was USD 25000000 while cost of remote sensing system is only

USD 25000 (Stedman, 1990). It also has many advantages over the previous systems based on its wavelength-specific approach, such as having a smaller size and higher sensitivity in the field when measuring the full range of vehicle emissions. Finally, the establishment of a data-base management subsystem makes the vehicle inspection and maintenance (IM) program more effective.

4 Conclusions

The on-road remote sensing system of vehicle emissions based on TDL technology is shown to be a quick and effective method of monitoring in-use vehicle exhaust pollutants under normal driving conditions. As the initial results based on the measured emission data showed that some effects such as slope, instantaneous speed and acceleration etc., have great impacts on the detectable rate of the system, as well as their influences on the pollutants emissions. So, the study of the relationship between these effects and emissions is valuable. And if the remote sensing can be integrated with the I/M program, a more meaningful information and vehicle emission reduction could be achieved. Furthermore, being a representative of real emissions, the large number of remote sensing data collected by the system can be used to study vehicle emission factors, forecast pollutants from vehicles in a certain region and build up the vehicle emissions pollution model.

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