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On-vehicle emission measurement of a light-duty diesel van at various speeds at high altitude

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HIGHLIGHTS

- On-vehicle measurements manifested that CO and HC decreased as vehicle speeded up.
- NOx and PM increased with vehicle speed at all altitudes.
- CO, HC, PM increased with altitude at all tested speeds.
- NOx revealed its peaks at 2400 m at all three altitudes.

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ABSTRACT

As part of the research on the relationship between the speed of a vehicle operating at high altitude and its contaminant emissions, an on-vehicle emission measurement of a light-duty diesel van at the altitudes of 1000 m, 2400 m and 3200 m was conducted. The test vehicle was a 2.8 L turbocharged diesel Ford Transit. Its settings were consistent in all experiments. Regulated gaseous emissions, including CO, HC and NOx, together with particulate matter was measured at nine speeds ranged from 10 km h^{-1} to 90 km h^{-1} with 10 km h^{-1} intervals settings. At each speed, measurement lasted for at least 120 s to ensure the sufficiency and reliability of the collected data. The results demonstrated that at all altitudes, CO and HC emissions decreased as the vehicle speed increased. However both NOx and PM increased with vehicle speed. In terms of the effects of altitude, an increase in CO, HC and PM was observed with the rising of altitude at each vehicle speed. NOx behaved different: emission of NOx initially increased as the vehicle was raised from 1000 m to 2400 m, but it decreased when the vehicle was further elevated to 3200 m.

1. Introduction

As people become more aware of environmental protection, they are keen to know more about vehicle emission and its possible threats to public health. Thanks to previous researchers and developers, vehicles churn out far less contaminants today. However, serious contaminant emissions are persistent under special operating conditions, such as at high altitude.

A high-altitude verification mechanism is absent from current type-approval procedures. Consequently, manufacturers can circumvent specific tunings for a vehicle's high-altitude performance. Emissions of a vehicle operating at high altitude can be significantly worse, a scenario that is already prevalent in mountainous regions in China. Decades ago, power de-rating of diesel engines operating in high altitude regions had been achieved (Dennis, 1971; Wu and McAulay, 1973). However, the more intractable problem of severe contaminant emissions had not been realized by the researchers until the early 1990s (Human et al., 1990).

Compared to vehicles operating at sea level, diesel engines running at high altitude could produce a larger amount of CO, HC, PM and aldehyde emissions. Human et al. (1990) measured the emission factors of a naturally aspirated diesel engine and a turbocharged diesel engine at a low altitude and a simulated high altitude. The results indicated that at 6000 feet, emissions of CO, HC, PM and aldehyde were 2–4 times higher than that measured at a low altitude, whereas a 10% decrease in NOx emissions was observed at 6000 feet. Chernich et al. (1991), comparing the smoke

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opacity of diesel trucks operating at sea level and at high altitude, showed that the opacity of high altitude operating trucks was 23 points higher than that of sea level operating trucks. The result was an ensemble average of 84 randomly selected samples. Using high altitude simulation constant volume sampling system, Chaffin and Ullman (1994) simulated the atmospheric pressures of three high altitudes and measured the engine emissions at each height. The results demonstrated that in both steady and transient tests, CO, HC, PM and smoke opacity increased as the simulated atmospheric pressure descended. As for NOx, it was insensible to the variation of atmospheric pressure in the transient tests, while it appeared a slightly negative correlation with increased altitude in the steady tests.

The majority of early works used engine test benches to study the impact of high altitude on engine emissions. However, as mentioned by Yanowitz et al. (2002), in a chassis dynamometer based research, it was hard to predict accurately the test outcomes by combining engine dynamometer based results and vehicle transmission models. The reason is that even small deviations in vehicle speed could lead to a pretty wide range of engine load changings. Therefore, it is more important to conducted real-world emission measurements of high altitude operating vehicles. Bishop et al. (2001) conducted an experimental survey of the emission of heavy-duty diesel trucks at five locations in America. By using remote measurement instruments, 5772 samples were collected in Bishop's survey, and a statistical increase in the emissions of CO, HC and NO with the rising of altitude were found. However, the inflation of NO seemed minor. A novel on-vehicle measurement of vehicle emissions at high altitude was conducted by Yin et al. (2013). They measured the regulated gaseous emissions and particulate matter of a light-duty diesel van at idle at several altitudes ranged from 70 m to 3200 m. Generally, emissions of CO, HC and PM emissions were higher during high altitude operations while NOx emissions measured near sea level and at high altitude were basically similar.

A few key works have studied vehicle speed's impacts on vehicle emissions at sea level. Zhai et al. (2008) established a vehicle specific power (VSP) model that included parameters such as vehicle speed, engine load and vehicle weight in order to assess the impacts of vehicle speed on emissions. In the tests, HC and NOx were positively correlated to larger VSPs (VSP could be recognized as another way to express vehicle speed if the test vehicle was uniformly driven). As for CO, generally it had a positive correlation with enlarged VSP as well, but when VSP was kept at a very high level, CO emission dropped. Besides, Joumard et al. (1995) and El-Shawarby et al. (2005) had established different emission models based on mean traffic speed for policy-making purposes. Similar to Bishop et al.'s survey, Kean et al. (2003) measured the emission of a variety of passing-by vehicles in a California tunnel by utilizing remote measurement algorithm. The results implicated that during uphill driving, both CO and NOx emissions increased with vehicle speed. The study also indicated that comparing to CO, NOx was less dependent on vehicle speed.

It's clear that, in the current state, our knowledge about the emission of high altitude operating vehicles is still inadequate for us to develop effective counter-pollution measures in these regions, which became a barrier for the daily supervision and management of vehicular emission. To deepen the recognition of the emission characteristics of high altitude operating vehicles, in this paper, the correlation between vehicle speed and regulated gaseous emissions together with particulate matter was investigated. At three high altitudes, contaminant emissions of an ERUO III light-duty diesel van were gauged and analyzed. All the tests were performed in real-world circumstances by adopting a portable emission measurement system.

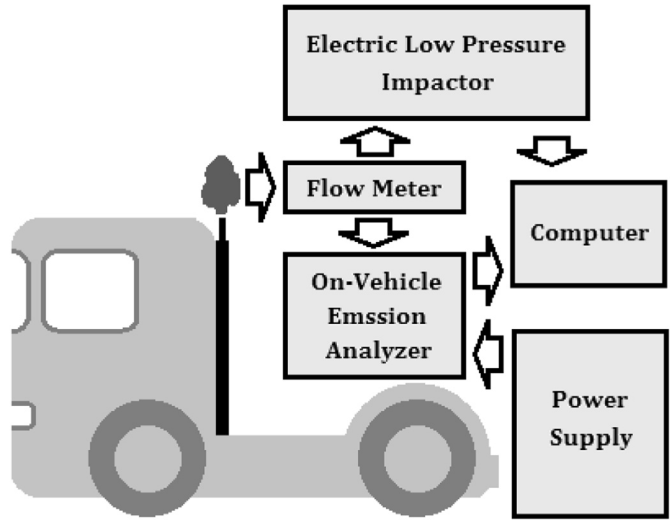

Fig. 1. Schematic of the PEMS in this present paper.

2. Apparatus and methodology

2.1. Portable emission measurement system (PEMS)

In early researches, some authors preferred to use simulation devices to simulate the low atmospheric pressure at high altitude. However, either electronic controlled intake and exhaust vacuum pumps or specially designed constant volume sampling system is not able to completely reflect the actual environment where a vehicle is operating on high altitude roads. In consideration of this, in this paper, both gaseous and particulate emissions were measured by a PEMS, which is a more favorable determination of real-world vehicle pollutions.

The PEMS configuration included a SEMTECH-DS analyzer from the Sensors Inc., which is dedicated to the on-vehicle measurement of regulated gaseous emissions. For the measurement of carbon oxides, non-dispersive infrared absorption algorithm was used. The measurement of NOx components followed the principle of non-dispersive ultra-violet. Hydrocarbon contents remained in the exhaust was measured by a hydrogen flame ionization detector. Resolution time of the emission analyzer was 1 ms, and the precision for each pollutant was, 10 ppm for CO, 0.01% for CO_2, 1.0 ppm C for HC and 1 ppm for NOx. In addition, weather condition, including atmospheric pressure, temperature and relative humidity was obtained from the weather station that was integrated in the analyzer. The analyzer also had an interior GPS module, which provided the vehicle speed and altitude information.

In parallel, an electronic low pressure impactor (ELPI) and a fine particle sampler (FPS-4000) by DEKATI were employed in to measure the particulate matter emission of the test vehicle. ELPI is able to measure the fine particles with aerosol diameter ranged from 7 nm to 10 μm. For the power supply and data acquisition, a 5 kW power generator and a notebook computer was adopted. In Fig. 1, a schematic of the PEMS was illustrated.

2.2. Test vehicle

Test vehicle of this current research was a Ford Transit registered in 2007. The test vehicle had a 2771 mL, in-line, 4-cylinder, inter-cooled, turbocharged, common-rail diesel engine without any after-treatment system. The engine could meet the Chinese National III emission standard (equivalent to Euro III). During the tests