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Emission profiling of diesel and gasoline cars at a city traffic junction

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ABSTRACT

In congested urban roads, cars must stop at intersections because of city traffic lights. As a result, pedestrians and traffic police personnel are exposed to pollutants emanating from the tailpipe of various vehicles at such city traffic junctions. In this study, various gasoline- and diesel-fueled cars complying with different emission standards were tested for their emissions in simulated city traffic junction conditions. The engine exhaust from these cars was subjected to physicochemical characterization at different engine speeds under no-load conditions. These engine conditions were chosen because the cars idle at different engine speeds at a city traffic junction. Gravimetric and real-time measurements were performed for the tailpipe exhaust sampled from these vehicles. Exhaust particles were collected on 47 mm diameter quartz filter papers and subjected to gravimetric analysis for determining the total particulate mass (TPM) and trace metals while the engines were operated at two different engine idling speeds, 1500 rpm (representing low idling) and 2500 rpm (representing high idling). At similar engine operating conditions, TPM and trace metals were lower for the exhaust from gasoline engines compared to the exhaust from diesel engines. Real-time measurements were performed for particle-bound poly-aromatic hydrocarbons (PAHs), particle number and size distribution, regulated gaseous emissions and smoke opacity of the exhaust at four different engine speeds, 1500, 2000, 2500, and 3000 rpm. Particle-bound PAHs showed a decreasing trend for the vehicles that complied with stricter vehicular emission standards. Higher particle peak number concentrations were observed for diesel exhausts compared to the results for gasoline exhaust. Regulated gaseous emissions were also compared.

Introduction

Automobile sector has been one of the most successful industrial sectors in India since 1990s, which coincided with economic liberalization of the country. Before the 1990s, the automotive industry was dominated by a few domestic manufacturers. However, it is now one of the fastest growing industrial sectors in India and includes many multinational companies. Two-wheelers including motorbikes, scooters, etc. constitute a major fraction of the total vehicular production in India today, followed by cars, and together these groups constitute 92% of the vehicles manufactured in India (SIAM, 2012). India's car market has emerged as the world's second fastest growing market after China. Following economic liberalization, people's increased purchasing power led to an increase in the demand for cars, which is expected to continue in the near future. Alongside this, manufacturers are required to employ advanced emission control technologies to meet stringent emissions regulations, which are being adopted in India and around the world.

Emissions from cars are currently controlled for regulated emissions including carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM). In addition to these regulated emissions, vehicles also emit unregulated emissions such as poly-aromatic hydrocarbons (PAH), aldehydes, and benzene-toluene-xylene (BTX), which are toxic to humans. Advanced emission norms, such as the Euro 5b emission standard, prescribe a limit for the total number of particles emitted from the engine per unit distance traveled, and further dimensions to this are expected to be added in forthcoming emission norms. Since, vehicle density in urban areas is constantly increasing, there is an urgent need to characterize and control unregulated emissions in addition to those which are already regulated.

Several researchers have examined the regulated and unregulated emissions from gasoline- and diesel-fueled passenger cars (Agarwal, Gupta, Dixit, & Shukla, 2013; Betha & Balasubramanian,

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2011; Chen et al., 2001; Gupta, Kothari, Srivastava, & Agarwal, 2010; Hu et al., 2009; Lu, Huang, Cheung, & Ma, 2012; Pakbin, Ning, Schauer, & Sioutas, 2009; Schauer, Kleeman, Cass, & Simoneit, 2002). Yan, Winijkul, Jung, Bond, and Streets (2011) predicted an overall reduction in global PM emissions originating from on-road vehicle exhaust until 2035, despite global increases in fuel consumption. Their study suggested that global PM emissions will decrease because of stricter enforcement of emissions norms and replacement of older, inefficient vehicles with a newer vehicular fleet having higher efficiencies. Hu et al. (2009) determined the emission factors for trace metals emitted by heavy-duty diesel vehicles under idling, transient and cruising conditions. In their study, particulates were collected on filter paper as well as by a personal cascade impactor sampler (PCIS) for total and water-soluble elemental analysis with results showing significant differences in trace metal emissions for different engine operating conditions. Gangwar, Gupta, and Agarwal (2012) employed a common rail direct injection (CRDI) engine to determine the organic carbon (OC), elemental carbon (EC), particle-bound PAHs, benzene soluble organic fraction (BSOF) and trace metals emitted from diesel and 20% biodiesel blends (B20). They observed that emissions of BSOF and trace metals decreased with increasing engine load. The peak emissions from a diesel exhaust of particle-bound PAHs were attained near intermediate engine loads.

Ravindra, Sokhi, and Van Grieken (2008) suggested that emission regulations should cover PAHs emissions because of their higher carcinogenic risks. Vouitsis et al. (2009) compared emission of trace metals and PAHs from three different light-duty vehicles. They observed a significant reduction in trace metal emissions by employing a diesel particulate filter (DPF) and reported that PAHs emissions were moderately lower for gasoline vehicles. In numerous studies (Heywood, 1988; Majewski & Khair, 2006; Pundir, 2007; Ulrich et al., 2012), it has been observed that PM emissions were relatively low for gasoline vehicles compared to those from diesel vehicles. However, number concentrations of emitted particles were found to be comparable for both gasoline and diesel vehicles (Agarwal, Gupta, & Kothari, 2011; Gupta et al., 2010).

With the increase in number of four-wheeler vehicles in urban areas of the developing world, traffic congestion is continuously increasing at traffic junctions where, all vehicles operate under no-load conditions at different engine speeds, while waiting for green light. Here, drivers, passengers, traffic police personnel and the surrounding population are exposed to harmful vehicular emissions. Therefore, there is a need to investigate the emission profiles of four-wheeler vehicles at a traffic junction. In the current study, physicochemical characterization is carried out on engine exhausts emanating from various diesel- and gasoline-fueled cars operating under no-load conditions at different engine speeds, as typically observed at a city traffic junction.

Experimental setup

In the present study, six different cars (three fueled with gasoline and three with diesel) were used for exhaust sampling. The vehicles were tested at different engine speeds operating under no-load conditions to simulate the situation of a typical city traffic junction (Fig. 1). Cars were categorized into two broad categories and were further classified based on emission standards (BS II, BS III, and BS IV) (Bharat Petroleum Corporation Limited). A simple labeling system was used to represent a specific type of car. An example is 4G1II, where 4 is the number of wheels; G indicates the vehicle is gasoline-fueled (as opposed to D for diesel); 1 is the vehicle number; and II is the vehicle emission standard e.g. Euro II in this case. Both gravimetric and real-time measurements were performed using the experimental setup shown in Fig. 1.

Table 1
Fuel specifications of gasoline and diesel (SIAM, 2014).

Property	Gasoline	Diesel
Density at 15 °C (kg/m^3)	720–775	820–845
Octane number/cetane number	91	51
Sulfur content (mg/kg)	50	50

A partial flow dilution tunnel was used for diluting the exhaust with pre-conditioned, heated and filtered air following the same process as in Dwivedi, Agarwal, and Sharma (2006). When the exhaust exited the tailpipe, it was rapidly diluted at a dilution ratio of 20 (see Eq. (1)) before the particulate sampling on the filter paper. Following EPA specifications, the diluted exhaust temperature was maintained at 52 °C.

$$\text{Dilution ratio} \quad (r) = \frac{[\text{undiluted exhaust CO}_2]}{[\text{diluted CO}_2 - \text{ambient CO}_2]}. \tag{1}$$

For gravimetric analysis, PM samples were collected on a 47-mm quartz filter paper for 1500 and 2500-rpm engine speeds at no-load condition. It was observed that 30 min of particulate sampling provided sufficient particulate deposits on the filter paper for further analysis. The particulate samples were analyzed for TPM, BSOF, and trace metals. An inductively coupled plasma optical emission spectrometer (ICP-OES) (Thermo Fischer Scientific: iCAP DUO 6300 ICP Spectrophotometer) was used for trace metal analysis for diesel and gasoline particulates as per the procedure followed by Chakraborty and Gupta (2010). The iCAP 6300-Duo ICP Spectrophotometer can detect 66 elements, with detection limits of less than 1 μg/L.

Real-time measurements were performed at the following four engine speeds: 1500, 2000, 2500, and 3000 rpm. Regulated gaseous components, particle-bound PAHs, particle number-size distribution, and smoke opacity were measured using online instruments. For particle number-size distribution, an engine exhaust particle sizer (EEPS, TSI 3090) was employed, which measured exhaust particles in the size range of 5.6–560 nm with number concentrations up to #10^8/cm^3. A photoelectric aerosol sensor (PAS2000, EcoChem), which operates on the principle of photo-ionization of particle-bound PAHs (Agarwal, Gupta, et al., 2013; Gangwar et al., 2012), did real-time measurement of particle-bound PAHs in the engine exhaust. Emission measurement was done using an exhaust gas emission analyzer (AVL: DiGas 444), while a smoke opacimeter (AVL: 437) was used for determining the opacity of the engine exhaust gas.

The fuel used was regular petroleum fuel (Bharat stage IV) and was purchased commercially from an authorized dealer in Kanpur, India. Table 1 shows the specifications of mineral diesel and gasoline available in the Indian market. The engine of each vehicle was operated at an idle condition for at least 10 min to attain thermal stabilization. Once exhaust temperature stabilizes, emission measurements were carried out. Table 2 outlines the relevant engine specifications of different vehicles used in this study.

Table 2
Selected engine specifications of tested vehicles.

Vehicle nomenclature	Emission compliance	Engine capacity (cc)	No. of cylinders	Rated torque & speed
4G1II	BS II	796	3	59 Nm @ 2500 rpm
4G2III	BS III	796	3	62 Nm @ 3000 rpm
4G3IV	BS IV	1197	4	113 Nm @ 4500 rpm
4D1II	BS II	2179	4	249 Nm @ 1600 rpm
4D2III	BS III	2179	4	290 Nm @ 1800 rpm
4D3IV	BS IV	1248	4	190 Nm @ 3000 rpm