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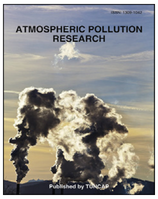

On-field and laboratory measurement of nanoparticle emission in the wake of gasoline vehicle

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ABSTRACT

Nanoparticle emission from gasoline driven vehicles is reported to be significantly lower compared to diesel vehicles. Accordingly, there is no threshold limit implemented by the regulatory authorities in India for gasoline driven vehicles. Recent studies however indicate that this is true as far as the mass concentration of the nanoparticles is concerned. The number concentration of nanoparticles particularly of smaller dimensions is reported to be significantly higher for gasoline driven vehicles under certain operating range of speed and load. Smaller the dimension of the particles more are their residence time in environment and more susceptible are these particles to be inhaled by human respiratory and cardiovascular system. Thus an estimate of the size distribution of nano-sized particulate matter emission from gasoline driven vehicle is of immense importance in context to Indian urban population. In this direction, laboratory measurements are reported for the nanoparticle size distribution emitted from a gasoline engine under different loading conditions. On-field measurements are carried out in the wake of a stationary vehicle under idling and throttling condition. Simultaneous measurement of vehicular acceleration and deceleration is also reported along with nanoparticle distribution in the wake of a moving vehicle. The measurements reported in this paper reveal the need for deciding threshold value of number concentration to be implemented for gasoline vehicles by the Indian regulatory authorities.

1. Introduction

Air quality deterioration has reached an alarmingly high level in developing countries like India. Automobile industry of India has undergone huge expansion in the recent past and is expected to be the third largest in the world by 2016 (IBEF, 2016). Automobile production reached a new high with a production of 23.9 million motor vehicles in the financial year 2015-16 which included 3.4 million passenger vehicles and 18.8 million units of two-wheelers being produced in the same year (IBEF, 2016). For the year 2015-16, India is the 6th largest car manufacturer and 8th largest commercial vehicle manufacturer (IIFL, 2016). Sixty out of sixty two metropolitan cities of India have exceeded World Health Organization (WHO) standards for particulate matter (PM) and an alarming 2.5 million premature deaths are caused annually in India due to particulate matter exposure (Ghosh and Goswami, 2014). The situation is expected to worsen in the coming future with total passenger traffic to reach 168,875 billion passenger kilometer in 2031-32 from 10,375 billion passenger kilometer in 2011-12 with road passenger traffic growth rate projected at 15 percent (ITR, 2014).

Owing to government of India's decision to link diesel to market rates narrowing the gap between gasoline and diesel vehicles (TWSJ, 2014), the sale of gasoline vehicles has picked up recently. The running cost of gasoline cars in India has dropped from Rs. 4.89/km in 2012 to Rs. 4.62/km in 2016. On the other hand the running cost of diesel cars in India has increased from Rs. 2.67/km in 2012 to Rs. 2.89/km in 2016 (TET, 2016). As a result the share of gasoline car sale in India has picked up from 48% in 2012 to 74% in 2016 while the share of diesel car sale has declined from 52% in 2012 to 26% in 2016 (TET, 2016). Emission from gasoline engines is thus as significant a threat to Indian urban cities, as is emission from diesel vehicles.

Incomplete combustion of fuel is the major cause of particulate

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matter (PM) emission from gasoline driven vehicles. Particulate matter forms during combustion and afterwards as carbon containing molecules solidifies due to condensation. In gasoline engines, soot (mainly elemental carbon and particle-bound organic carbon, Srivastava and Agarwal, 2008) formation is not very prevalent as in the case of diesel engines but is formed in large quantities under relatively rich air-fuel ratios (Harris and Maricq, 2001). Over-fueling can occur under cold start conditions when engines are run rich to provide sufficient fuel for burning (Ristimäki et al., 2005). Also for greater power and for component temperature protection under high acceleration rates or higher loads, an extra amount of fuel is needed to be injected (Lee et al., 2008).

Particulate matters like sulphates and phosphates are formed from combustion of trace levels of sulphur and phosphorus found in engine oil and fuel. The sulphur content of gasoline is 50 ppm as per Bharat Stage-IV (BS-IV) norms. This reduces the formation of sulphates from the fuel. However, gasoline engine oil contains comparatively significant sulphur (and phosphorus) compounds resulting into the formation of particulate matter due to combustion (Ronkko et al., 2006). Positive Crankcase Ventilation present in gasoline vehicles to remove excess hydrocarbons in the hot crankcase is also responsible for inducting particulate matter precursors and oil into combustion chambers. Organic particulate matter release is also significant due to oil consumption as oil is a high molecular weight hydrocarbon and is mostly present in uncombusted droplets. Other form of particulate matters such as metallic oxides, metal sulphates and nitrates are also formed from combustion of trace metals present in gasoline fuel and engine oil (Corrêa and Arbilla, 2005).

Particulate matter (PM) emissions have been an issue of concern for diesel engines since long (Pope et al., 1995; Myung et al., 2009). The use of Diesel Particulate Filters (DPF) has contributed to the decrease in particulate matter emissions (Biswas et al., 2009; Mohr et al., 2006). Although particle size distributions for diesel engines using DPF look more similar to those for gasoline-powered engines, emissions of ultrafine particles are of greater concern for gasoline engine (Harris and Maricq, 2001; Lee et al., 2008; Mathis et al., 2005; Morawska et al., 2008). The port fuel technology used in gasoline vehicles is rapidly being replaced by gasoline direct injection (GDI) engines (Alkidas, 2007) due to better fuel economy and reduction in emission of greenhouse gases. The major drawback of GDI technology however is increased emission of particle number concentration due to fuel impingement on surfaces of piston and cylinder, resulting in the formation of partially fuel rich zones (Bonandrini et al., 2012; Maricq et al., 1999b; Sementa et al., 2012). When compared to particle number concentration released from modern day diesel exhaust fitted with diesel particle filter, the particle number concentration released from GDI engines is relatively higher (Mathis et al., 2005).

In general, diesel engine emissions contain particles with greater aerodynamic diameters compared to emissions from gasoline vehicles (Ristovski et al., 2000). Harris and Maricq, 2001 reported that the diesel engine particle size distributions vary with mean diameters in the range of 60–120 nm, while mean diameters for gasoline vehicles are in the range of 40–80 nm. In a more recent study on Indian vehicles it was reported that the peak concentration of emitted particles from gasoline vehicles lies in the nanoparticle range and with increase in size of the particle, the peak concentration decreased (Agarwal et al., 2015). As reported by Gang et al. (2014), the peak particle concentration for the PFI car is below 39 nm.

Toxicology studies show that nanoparticles can penetrate the respiratory system of humans easily and can enter into the lungs, blood tracts and even brain, and can cause death in extreme case (Peters et al., 2000; O'Connor et al., 2008; Li et al., 2013; Mehel and Murzyn, 2015). In a more specific study, Geiser and Kreyling, 2010 has depicted that the total health hazard to human body parts is more due to smallest size of particles. The nanoparticles in the diameter range of 3–10 nm can affect even the bronchi while the alveoli are affected by particle sizes below 30 nm. Stricter emission standards are thus being developed and implemented for emissions from gasoline engines although with some degree of variations from country to country. Since 2004, United States of America has adopted same particulate mass standards for diesel as well as gasoline vehicles. Euro 5 standards set up a limit for particle mass emissions from GDI gasoline engine since 2009. Euro 6 norms have limits for particle number concentration also.

In order to help in developing similar threshold limits for Indian environment, the present research is an attempt to estimate the number concentration and size distribution of nanoparticles released from gasoline driven vehicles running on Indian roads. Nanoparticle number concentration in the size range of 10–420 nm is measured from a gasoline vehicle running on Indian urban road. The purpose of measuring nano-sized particles in the above mentioned range is due to the maximum health hazard associated with the smallest size of the particulate matter. In what follows in this paper, the experimental test facility, instruments used and the sampling procedure are discussed in section 2. Section 3 presents results and discussion on nanoparticle number and size distribution due to variation in engine load, in the near wake of an idling, throttling and moving gasoline vehicle. Discussion is also presented in this section for the simultaneous measurement of vehicular acceleration and deceleration and associated nanoparticle emission in the near wake regime. Section 4 reports the major observations and conclusions while section 5 is a list of suggestions for Indian regulatory authorities in context to nanoparticle emission from gasoline vehicle.

2. Experimental section

2.1. Laboratory test facility and instrumentation

Laboratory experiments are carried out on a 3 cylinder, 4 stroke gasoline engine test rig. The engine has Multi Point Fuel Injection system (MPFI), with a power of 27.6 kW at 5000 RPM and a torque of 59 Nm at 2500 RPM. The 796 cc cylinder has a compression ratio of 9.2 with stroke of 72 mm and bore of 66.5 mm. The engine is connected to eddy current type dynamometer for loading. The test rig consists of the engine, dynamometer, the control panel for controlling supply of fuel and air. The measuring unit consists of rotameters for measurement of air, fuel and cooling water flow rates.

The exhaust from the gasoline engine is passed through a dilution system (following the work of Brown et al., 2000) which has dilution ratio sufficient to approach atmospheric dilution conditions. Fig. 1 shows the schematic sketch of the gasoline engine test rig along with the dilution system. The vehicular exhaust from the tailpipe is delivered to the dilution tunnel through a short (1m) heated sample line. On the basis of measured CO_2 concentration of raw exhaust and that of the diluted exhaust, the dilution ratio (~50) is calculated. A flue gas analyzer (model: Testo 340) is used for measurement of CO_2 concentrations. The conditions of the sampling system minimize the volatile nucleation mode formation. However, semi–volatile nucleation mode formation could not be excluded. The measurements are carried out for constant RPM operation of the engine and for a varying load. For loading the engine, an eddy current, water cooled, dynamometer is used along with a loading unit (measured in terms of torque in Nm).

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