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A review on nanoparticle dispersion from vehicular exhaust: Assessment of Indian urban environment

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ABSTRACT

A comprehensive review is reported on the extent of release of ultrafine and nanoparticles from vehicular exhaust on Indian roads, the mechanism of evolution of these particles and the influence of key fuel and meteorological parameters on their evolution and dispersion. Consolidated understanding developed based on the available literature on nanoparticle formation and transformation processes is presented pictorially in the form of a schematic diagram. Influence of various parameters on the evolution of nanoparticles is elaborated using the present scientific understanding of dispersion mechanisms in the near and far field of vehicular exhausts. Inferences are drawn for the influence of Indian road conditions and atmospheric conditions on the dispersion of these evolved nanoparticles. Broad based suggestions are outlined for the Indian regulatory authorities so as to minimize the hazardous influence of such particulate emissions to urban population.

1. Introduction

Indian cities have been graded in terms of their air pollution status as per the National Air Quality Index (NAQI) released by (CPCB, 2016a). Table 1 summarizes the grading criteria and air quality index of some of the cities of India. It is observed that the air quality in most of the Indian cities is graded between very poor to poor. Exhaust from vehicles is a major source of air pollution in urban India (Mahalakshmi et al., 2014). This is because of exponential growth of vehicles on urban Indian roads. The number of cars in India is projected to be in the range of 45–60 million by 2025 (TERI, 2014). The expected number of cars would be about 10 million by 2025 in capital city of Delhi alone (Ramachandra and Shwetmala, 2009; TERI, 2014). The increased number of vehicles in Indian cities is resulting in alarming rate of rise of air pollution levels in these cities.

Major constituent of vehicular pollutants include hydrocarbon compounds, carbon monoxide, nitrous oxides, carbon dioxide and airborne particulate matters majority of whose sizes are significantly less than 1 μm. The particulate matter emission from vehicular exhaust represents a mixture of fine, ultrafine, and nanoparticles. Toxicologists define ultrafine particle as those with sizes below 100 nm, fine particles as those below 1000 nm and coarse particles as those above 1000 nm (Oberdörster et al., 2005). Particles below 300 nm are usually referred as nanoparticles (Kumar et al., 2009). Regulatory agencies however use terms such as PM_{10}, $PM_{2.5}$ and PM_1 for mass of particulate matters below 1000 nm, 250 nm and 100 nm respectively. Mass concentration of 10 μg/m^3 for $PM_{2.5}$ contains as many as 2.4 million 20-nm particles/cm^3 (HEI, 2013). Smaller diameters of these particles enhance their probability to penetrate into the human respiratory and cardiovascular systems thereby causing lung diseases and increase in blood coagulability (Donaldson et al., 2005; Jonathan et al., 2012; Pope et al., 1995; Pope and Dockery, 2006; Zhang et al., 2008). Since nanoparticles have higher surface area per unit mass, these particles interact easily with other biological systems and help toxic chemicals to penetrate cell membrane thereby affecting non-respiratory organs in human body like kidney, brain, liver, spleen and even skin (Forbe et al., 2011; Kreyling et al., 2006; Maier et al., 2006; Mohan et al., 2013; Oberdörster et al., 2005). Study carried out in Delhi suggested that exposure to nanoparticles (Kumar et al., 2011a) and other pollutants (Gurjar et al., 2010) emitted from vehicles causes ~ 11250 excess deaths in Delhi every year. Fig. 1(a and b) shows the status of acute respiratory illness and death due to respiratory diseases and lung cancer in India and especially in Delhi due to increase in concentration of PM_{10} during 2009–2012 as reported in TERI (The Energy and Resources Institute) policy report 2014 (TERI, 2014).

In addition, particulate matters are one of the most hazardous pollutants in context to their strong influence on global climate (Strawa et al., 2010). Particulate matter of size 100–1000 nm are comparable to the wavelength of visible light and are responsible for reduction in urban visibility (Hujia et al., 2013; Jung et al., 2009; Kim et al., 2006;

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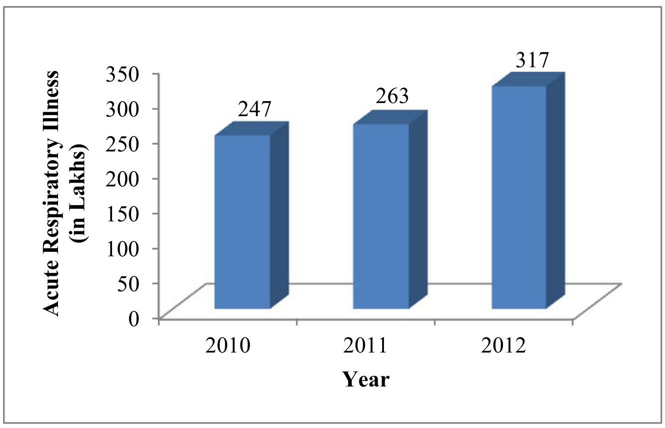
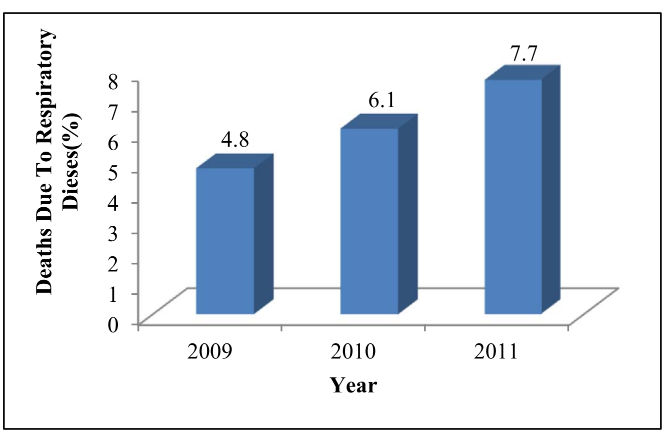
Table 1
Average Air quality Index (AQI) of Indian cities and their respective grading (CPCB, 2016a).

Sr. No	Cities	Months	Average AQI	Grading
1	Delhi	Jan-16	370	Very Poor
		Feb-16	293	Poor
		Mar-16	238	Poor
2	Patna	Jan-16	390	Very Poor
		Feb-16	290	Poor
		Mar-16	198	Moderately polluted
3	Lucknow	Jan-16	363	Very Poor
		Feb-16	317	Very Poor
		Mar-16	179	Moderately polluted
4	Kanpur	Jan-16	364	Very Poor
		Feb-16	261	Poor
		Mar-16	194	Moderately polluted
5	Agra	Jan-16	377	Very Poor
		Feb-16	233	Poor
		Mar-16	143	Moderately polluted

Good	Satisfactory	Moderate	Poor	Very Poor	Severe
0–50	51–100	101–200	201–300	301–400	> 401



(a)



(b)

Fig. 1. (a) Status of acute respiratory illness and (b) deaths due to respiratory diseases and lung cancer in Delhi during 2009–2012 due to increase in PM_{10} (TERI, 2014).

Seinfeld and Pandis, 2006). Also the particulate matter emission increases with local atmospheric temperature and may result in catastrophic phenomena like acid rains. Particulate matters may be carried by wind over a long distance and get deposited on ground or water. These harmful implications are required to be controlled.

Some important questions that arise in context to Indian urban planning are: how the toxicity of these particulate matters are to be measured (or monitored) and how are the regulatory laws to be framed to reduce their release in urban Indian cities. Present practice is to control the particulate matter in terms of their mass concentration with limiting values for PM_{10} or $PM_{2.5}$ (CPCB, 2016b). Even for a small mass concentration, the particulate number concentration for smallest size particles can be significantly large. Smallest diameter particles with more surface area per unit mass can absorb more carcinogenic organic compounds and have largest capability to penetrate the cell membrane. Larger number of such particles is thus hazardous to human (Forbe et al., 2011; Mohan et al., 2013). These smallest size particles ($\leq$100 nm) make up about 99% concentration of the total number of nanoparticles in ambient air with negligible mass (Kittleson, 1998) and 85% of this number concentration comes from vehicles in the urban environment (Kumar et al., 2011b). Thus particle number concentration becomes an important parameter to be measured and monitored.

Modification in emission standards to Bharat stage IV in many metro cities and associated improvement in fuel technology, advancements in engine design and after treatment emission systems have brought down the concentration of mass of emitted nanoparticles. However the number concentration is yet not tackled. No emission inventories for nanoparticles are presently available for developing countries like India (Krishna, 2012). Thus to combat the effect of nanoparticles released by the vehicles in countries like India and to develop an exhaustive emission inventory for the same, it is essential to understand the process of evolution of these nanoparticles from the exhaust of vehicle and the influence of various factors which affects the evolution and dispersion of these nanoparticles in Indian urban environment. The present article is an attempt in this direction. The major components of the present paper are:

1. A pictorial representation of the present scientific understanding of the complex transformation processes associated with the evolution of nanoparticles from vehicular exhaust and their subsequent dispersion in the ambient air.
2. Analysis of the influence of fuel, fuel conversion efficiency, vehicular motion and traffic congestions in Indian cities on the evolution and dispersion of nanoparticles and to comment on the influence of implementation of vehicular norms on nanoparticle mass and number concentration.
3. Analysis of the influence of meteorological parameters on the evolution process of nanoparticles from vehicle exhaust, their size and modal distribution and subsequent dispersion and correlate them to meteorological factors in Indian urban cities.
4. Assessment of seasonal characteristics of nanoparticles released from vehicle and associated health hazards in terms of exposure to Indian urban environment.
5. Assessment of the existing mitigation measures and control standards in urban India and suggest new measures and control standards to regulatory authorities of India.

In what is discussed in this article, section-2 deals with data associated with release of nanoparticles from vehicular exhaust in urban India, section-3 deals with transformation processes associated with nanoparticle evolution. Section-4 deals with the influence of key fuel parameters on the formation of nanoparticles. The consequences of Indian meteorological conditions on distribution of size and chemical composition of nanoparticles is discussed in section-5. Effect of vehicular dynamics, road conditions and seasonal variations on nanoparticle dispersion is discussed in Section-6. Seasonal characteristics of nanoparticles released from vehicle are discussed in section 7. Section 8 is an assessment of Indian regulatory control measures. Section-9 deals with policy changes associated with number concentration. Section-10 summarizes the future research needs in India to combat the vehicular nanoparticles.