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Review

Toward a better understanding of the impact of mass transit air pollutants on human health

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HIGHLIGHTS

- Efficient transport system is an essential step toward sustainable urban development.
- The effect of traffic-related air pollutants (TRAP) on human health is significant.
- The overall health conditions of pedestrians in a localized area were assessed.

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ABSTRACT

Globally, modern mass transport systems whether by road, rail, water, or air generate airborne pollutants in both developing and developed nations. Air pollution is the primary human health concern originating from modern transportation, particularly in densely-populated urban areas. This review will specifically focus on the origin and the health impacts of carbonaceous traffic-related air pollutants (TRAP), including particulate matter (PM), volatile organic compounds (VOCs), and elemental carbon (EC). We conclude that the greatest current challenge regarding urban TRAP is understanding and evaluating the human health impacts well enough to set appropriate pollution control measures. Furthermore, we provide a detailed discussion regarding the effects of TRAP on local environments and pedestrian health in low and high traffic-density environments.

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1. Introduction

Globally, growth in mass transit transportation systems has paralleled the rapid economic development in the last 30 years (Kim and Shon, 2011). An efficient transport system is an essential step towards sustainable urban development. This economic growth has resulted in severe congestion in commuter train stations and on arterial roads (Baldauf et al., 2013; Calderon et al., 2008; U.S. EPA, 2015). Drivers, passengers, cyclists, pedestrians, and road construction workers are all exposed to traffic-related air pollutants (TRAPs) that pose potential health risks. Despite numerous efforts devoted to the control of TRAP emissions, they continue to be of concern to both human health and the local ecology, especially in developing countries (U.S. EPA, 2015).

Modern spark plug internal combustion engines equipped with electronic control modules (ECM) are designed to operate leaner than the stoichiometric air/fuel ratio (A/F = ~15 w/w), in order to minimize emissions and improve thermal efficiency. In developing countries, however, engines often run “rich” (e.g., AF <15). Gasoline engines running rich emit unburnt hydrocarbons (HC) and more incomplete combustion by-products, including carbon monoxide (CO). A gasoline engine running “lean” (A/F > 15 w/w) will have a marginally reduced power output but will have more complete combustion. Diesel engines (constant induction volume and variable injected fuel mass) typically operate under lean A/F conditions, especially at low torque output. In general, emissions from gasoline engines increase with fuel consumption rate (i.e., $g.s^{-1}$) and decrease with engine power output for a fixed fuel consumption rate (Baldauf et al., 2013; Calderon et al., 2008; U.S. EPA, 2015). The main products of hydrocarbon combustion are CO_2 and H_2O with some CO. Oxides of nitrogen (NO and NO_2) are produced during high-temperature combustion (Baldauf et al., 2013; Calderon et al., 2008). The rate of NO_x production increases with increasing engine compression ratio (CR) (higher temperatures from adiabatic heating during the compression stroke) and at higher thermal efficiencies (Gandhi et al., 2003).

Recently, Volkswagen (VW) has been under investigation in the USA over allegations that a “cheat device” had been fitted to its turbodiesel engines (500,000 in the USA and 11 million worldwide) to sense when the vehicle was being laboratory tested and, at such times, activate pollution control devices to ensure compliance with the Clean Air Act. Under real-world driving conditions, however, the pollution control device was not active, and NOx emissions were ~40 times higher than under laboratory test conditions (https://en.wikipedia.org/wiki/Volkswagen_emissions_scandal, viewed January 2017). However, even with the pollution control devices activated, the on-road vehicle performance, fuel economy, and emissions were notably worse than under laboratory test conditions, despite the VW “clean diesel” performance marketing. As diesel engines have higher CR > 15, the temperature during the power stroke will be higher (due to adiabatic heating) so that the formation of NO becomes favorable in the endothermic reaction $N_2 + O_2 \leftrightarrow 2NO$. A number of other diesel car manufacturers are also implicated in the use of “cheat devices”. Increased thermal efficiency and lower CO_2 emissions came at the expense of increased NOx emissions. In 2014, Kia and Hyundai paid a USD100 M civil penalty for deliberately misrepresenting/understating to the US EPA the CO_2 emissions of their vehicles in the USA (i.e., using the best 3 results instead of the fleet average for a given model) (U.S. EPA, 2014a).

TRAP- emissions can be reduced by (i) promoting more complete combustion; (ii) recirculating exhaust gas back into the engine (EGR); and (iii) installing an exhaust catalytic converter (Krzyzanowski et al., 2005; U.S. EPA, 2014b; 2015). TRAP emission factors per unit distance driven in urban areas are high because of frequent “stop-start” events in heavily congested traffic situations (Krzyzanowski et al., 2005). Most countries have adopted strict pollution control guidelines for air quality control as illustrated in Fig. 1. This figure presents the combined reductions in the six most common air pollutants (carbon monoxide, non-methane hydrocarbons, nitrogen oxides, sulfur dioxide, and particulate matters (PM_{10} and $PM_{2.5}$)) from all U.S. combustion sources (U.S. EPA, 2014b, 2015 Air Quality Trends). In 2016, the US EPA documented the relative pollution contributions for key index pollutants (e.g., particulate matter ($PM_{2.5}$, PM_{10}), volatile organic compounds (VOCs), SO_2, NOx, NH_3, and elemental carbon (EC)) among diverse sources (e.g., stationary fuel combustion (e.g., electric utilities and industrial boilers), major industrial processes (e.g., metal smelters, petroleum refineries, and cements kilns), traffic activities, and other miscellaneous non-road mobile sources (e.g., recreational/construction equipment, marine vessels, aircraft, and locomotives) (Fig. 2) (U.S. EPA, 2016).

The objective of this review is to investigate the impact of TRAP on human health for people living in heavily traffic-congested urban areas. To this end, particular emphasis was placed on the health effect of nearby emission sources on people affected most sensitively by TRAP (e.g., pedestrian and bicyclist) and on the surrounding environment. Thus, our study was carried out to assess the relationship between human health and TRAP emissions index (as reported by different regulating and monitoring agencies around the world) and toxicity effects. Lastly, the overall health conditions of pedestrians in a localized area were assessed on the basis of pollutant concentrations and other relevant parameters reported in the literature.

2. Toxic airborne pollutants in TRAP

In urban areas, vehicle tailpipe emissions contribute approximately 30% of the daily fine PM loading (by mass), i.e., $PM_{2.5}$, aerodynamic diameter < 2.5 μm (U.S. EPA, 2015; Krzyzanowski et al., 2005). Additional sources of particulate emissions on the road include the re-suspended road dust and wear from tires and brake pads, particularly in the coarser PM fractions ($PM_{2.5\text{-}10}$). Figs. 3 and 4 show the temporal trends in vehicle-generated PM in the U.S. between 1990 and 2011 (U.S. EPA, 2014b). Vehicle pollutant emissions depend on such variables as vehicle type (light-vs. heavy-duty), age, operating conditions, effectiveness of exhaust pollutant control devices, quality and type of fuel used, meteorological conditions, and engine lubricant emissions (U.S. EPA, 2014b; 2015). In Europe from 2000 to 2010, the relative contribution from non-tailpipe emissions increased from 2 to 21% for $PM_{2.5}$, while it went from 21 to 33% for PM_{10} (Sundvor et al., 2012). Interestingly, emissions of key air pollutants including $PM_{2.5}/PM_{10}$, VOCs, O_3, SO_2, NOx, NH_3, and CO declined over 60% as per the implementation of