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Sound wall barriers: Near roadway dispersion under neutrally stratified boundary layer

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A R T I C L E I N F O

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A B S T R A C T

With the passage of California Senate Bill 375, which motivates infill development near transit hubs, there is the potential to increase vehicle congestion in residential communities and increase in human exposure to toxic mobile source pollutants. Among all the mitigation strategies that protect near roadway residents from health-affecting vehicular emissions (e.g. separating sensitive receptors from high traffic roadways), this paper discusses the impact of sound wall barriers (SBs) in reducing the air pollution exposure of nearby residents. To date, there have been some studies done to understand the impact of these structures on dispersion of vehicular emissions; however, no definitive conclusion has been drawn yet. The main objective of this paper is to provide more information and details on flow and dispersion affected by barriers through a systematic laboratory simulation of plume dispersion using a water channel. Three sets of experiments were conducted: (1) plume visualizations, (2) plume concentration measurements, and (3) flow velocity measurements. Results from this study shows that the deployment of sound barriers induces a recirculating flow over the roadway which transports the surface released emissions to the upwind side of the roadway, and then shifts the plume upward through an induced updraft motion. Plume visualizations clearly demonstrate that the presence of SBs induce significant vertical mixing and updraft motion on the roadway which increases the initial plume dilution and plume height and consequently results in reduced downwind ground level concentrations. Although different SB configurations result in different localized flow patterns, the dispersion pattern does not change significantly after several SB heights downwind of the roadway.

Introduction

Numerous epidemiological studies have shown that long-term exposure to outdoor air pollution increases the risk of respiratory diseases, birth defects, premature mortality, cardiovascular disease, and cancer (Dockery and Pope, 1994; Harrison et al., 1999; Wilhelm and Ritz, 2003; Peters et al., 2004; Jerrett et al., 2005; McConnell et al., 2006). Houston et al. (2006) showed that more than 24,000 childcare centers in California are within 200 m of highly trafficked roadways with more than 50,000 vehicles per day. A statistical analysis has shown that children diagnosed with asthma are more likely to live within 500 m of major roadways (Edwards et al., 1994).

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As part of the California climate action goals to reduce greenhouse gas (GHG) emissions (Assembly Bill 32; http://www.arb.ca.gov/cc/ab32/ab32.htm), the California Air Resources Board has adopted a land-use reform called SB375 (http://www.arb.ca.gov/cc/sb375/sb375.htm), which is a landmark legislation that aligns regional land use, transportation, housing, and greenhouse gas reduction planning efforts. This legislation requires the Metropolitan Planning Organizations to prepare sustainable community strategies to reduce the miles traveled by passenger vehicles with the goal of reducing the GHG emissions. Following this land-use reform, there is a potential to increase in the number of people living near high traffic roadways. Although California state law restricts the siting of new schools within 500 feet of a highly trafficked freeways and urban roads (http://www.arb.ca.gov/ch/handbook.pdf), there is no such requirement on residential communities. Therefore, air quality agencies are looking for other mitigation options to avoid the possible increase in the near-roadway exposure due to implementation of SB375. One of these strategies that has recently received more attention are roadside structures.

Although the primary purpose of roadside structures, such as sound barriers (SBs) and vegetation is to reduce noise, they can have a significant impact on the dispersion of pollutants by enhancing the turbulent mixing and raising pollutants further from the ground level. In addition, roadside vegetation can improve air quality by removing and filtering particulate matter and increasing the deposition of heavy metals (Beckett et al., 1998; Bowker et al., 2007; Brantley et al., 2014). Numerous field (Veranth et al., 2003; Bouvet et al., 2007; Pardyjak et al., 2008; Finn et al., 2010; Mao et al., 2013), wind tunnel (Heist et al., 2009) and numerical studies (Bowker et al., 2007; Steffens et al., 2013; Speckart and Pardyjak, 2014) have been conducted to address the impact of SBs and surrounding vegetation on the dispersion of traffic related emissions. It has been shown that for low wind speed and stable atmospheric condition, SBs can trap pollutants on the upwind side, increasing on-road pollutant concentrations (Finn et al., 2010; Baldauf et al., 2008). Baldauf et al. (2008) also showed that due to the finite length of the SBs some pollutants may be channeled into the leeward region of the SB, increasing the ground-level concentrations downwind of the barrier. The *Near Roadway Tracer Study* (NRTS08) conducted at Idaho Falls, Idaho by the National Oceanic and Atmospheric Administration (NOAA) shows that a concentration decrease of up to 50% compared with an unobstructed roadway can be achieved with different roadway configurations (Clawson et al., 2009; Finn et al., 2010). The results also indicate that increasing the atmospheric stability can reduce the effectiveness of SBs by increasing ground-level concentrations.

The effect of roadway elevation relative to the surrounding terrain has been investigated in the US Environmental Protection Agency wind tunnel (Heist et al., 2009). It has been shown that the smallest reduction in ground-level concentration occurs for elevated roadways and the maximum decrease happens in the case of depressed roadway with SBs on the sides. Bussoti et al. (1995) showed that broadleaves and small needle conifers are the most efficient species for eliminating heavy metal particles by enhancing deposition and preventing them from being transported farther downwind. Results from the model by Bowker et al. (2007) reveal that the presence of both SBs and vegetation can significantly reduce the concentration downwind by producing more turbulence and mixing. The study also stated that, with the presence of SBs, a more uniform and vertically well mixed plume can be observed (Bowker et al., 2007).

Most of the above-mentioned studies are more focused on the overall impact of SBs in reducing the ground level concentrations and do not sufficiently describe how these structures modify dispersion in terms of flow and turbulence. A thorough understanding on the direct impact of SBs on flow and dispersion can significantly help air quality modelers in development of dispersion models that can accurately predict the human exposure in the areas close to highways. Furthermore, most of these studies do not describe the impact of SBs under wind directions other than perpendicular to the SBs. Non-perpendicular wind directions can induce channeling between the SBs, which may be important in transferring most pollutants to less sensitive areas in order to decrease human exposures. Clawson et al. (2009) was one of the very few studies that investigated the impact of sound barriers under non-perpendicular approach flows; however, this study was only focusing on a single barrier configuration, which is not capable of generating channeling flow. Heist et al. (2009) investigated limited configurations that were all dominated by recirculating flow between the SBs, and only a perpendicular wind direction was investigated. Note that the simple model utilized by Heist et al. (2009) cannot reproduce channeling.

The present study aims to delineate the effects of various SB configurations on near-roadway dispersion through systematic water channel simulations. Laboratory simulations for dispersion of vehicular emission in the presence of SBs are investigated through (1) plume visualization and (2) concentration measurements. These results are accompanied with detailed flow measurements, which are needed to interpret the visualized plume patterns and measured ground level concentrations. The experimental setup and measurement techniques are described in Section 'Laboratory setup'. Section 'Laboratory experiments' presents results from all tested configurations. Visualization results are in Section 'Plume visualization', followed by concentration measurements in Section 'Concentration measurements' and velocity measurements in Section 'Velocity measurement'. Summary and conclusions are given in Section 'Summary and conclusion'.

Laboratory setup

Water channel

The water channel has a test section that is 1.5 m long, 1 m wide and 0.5 m deep. Water is circulated through the channel test section using a 20 HP axial pump (Carry Manufacture, Inc), which can produce a maximum mean velocity of 0.5 m s^{-1} in the test section. Velocity is controlled through a variable frequency controller with a resolution of 1/100 Hz. Flow