A Field and Modeling Study to Assess the Potential Mitigation of Near-Road Air Pollution by Vegetative and Structural Barriers

Extended Abstract #861

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INTRODUCTION

Recent modeling and field studies have demonstrated that roadside structures such as noise barriers or tree stands, may significantly affect the local-scale transport of on-road emissions to areas located adjacent to major roadways.[1-4] When directly downwind of a major roadway, concentrations of air pollutants associated with fresh traffic emissions (carbon monoxide and ultrafine particles) were lower in areas located behind a noise barrier relative to simultaneous measurements in an open field.[1] A wind tunnel experiment also confirmed decreases in ground-level concentrations with the presence of a roadside barrier relative to a flat terrain case.[3] However, for more complex geometries, such as the addition of trees to a street canyon, modeling results predict that the barrier location may cause either improved or degraded air quality along roadside pedestrian walkways.[5-7]

In order to better understand the effects of barriers on near-road air quality, US EPA Office of Research and Development is conducting a multi-faceted research study bridging from field measurements to modeling. Mobile monitoring field measurements were conducted at three roadside locations in North Carolina – two sites with vegetative barriers and one with a brick sound wall. In addition, wind tunnel experiments were conducted to observe the penetration efficiency of fine and coarse particles through evergreen vegetation. Finally, a computational fluid dynamics model of a roadway was developed, simulating a six-lane highway and a single-lane access road parallel to the highway, which are separated by a solid or porous barrier.

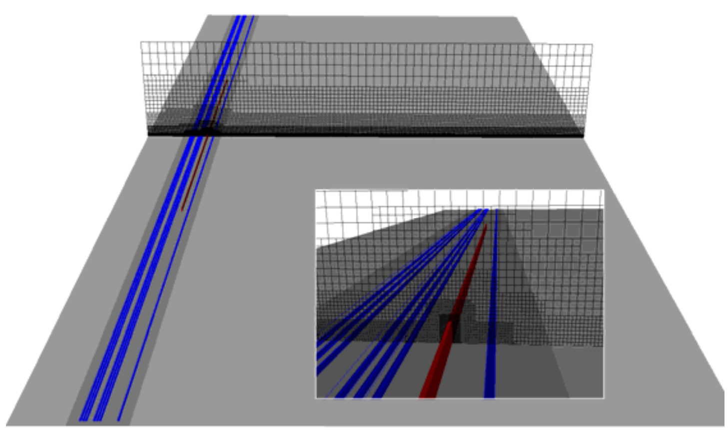
OVERVIEW

Experimental Methods

Computational Fluid Dynamics Modeling

Computational fluid dynamics (CFD) modeling, using FLUENT commercial code (www.fluent.com) , was applied to study the effects of various roadside solid barrier scenarios on near-road air quality. A base road model was evaluated against wind tunnel experimental data[3] in order to determine the most appropriate turbulence model for near-road dispersion modeling. The 3D CFD model includes a six-lane divided highway as the primary source for traffic-related emission and turbulence, with an additional single lane access road as an optional second source of emissions and turbulence (Figure 1). A 750 m long roadside solid barrier is located adjacent to a section of the roadway, with barrier-free regions on either end. The model resolution ranged from 0.25 m cells near the barrier and ground surface to 8 m cells, with a total of about 30 million cells over the modeling domain.

Figure 1. CFD solid barrier model, showing the mesh resolution along the XZ plane



Wind Tunnel Experiment

Wind tunnel experiments were conducted to observe the penetration efficiency of particles through vegetation. The experiments were conducted using EPA's Aerosol Wind Tunnel facility located in Research Triangle Park, North Carolina, filling a crosssection of 1.75 m x 1.45 m with two vegetative barriers of different characteristics – needle leaf (*Arborvitae*) and broad leaf (*Camellia sasanqua)* evergreen trees (Figure 2). A mixture of ISO 12103-1, A2 Fine Test Dust and ISO 12103-1, A4 Coarse Test Dust (Powder Technology, Inc., Burnsville, MN) was introduced upwind of the vegetative barrier using an aerosol injection system that includes charge neutralization. Particle size distributions were measured upwind and downwind of the vegetative barrier using a Scanning Mobility Particle Sizer (SMPS, TSI, Inc.) coupled with a Condensation Particle Counter (CPC, TSI, Inc.) as well as an Aerodynamic Particle Sizer (APS, TSI, Inc.), with wind speeds set at a range of 1-4 m/s. Barrier physical parameters and leaf area index (LAI, using an LAI2000, Li-Cor Biosciences) were documented for each vegetative type. Qualitative flow visualization was also performed by dispersing smoke through the test section.

Figure 2. Wind tunnel experiment with needle leaf vegetative barrier

Field Campaigns

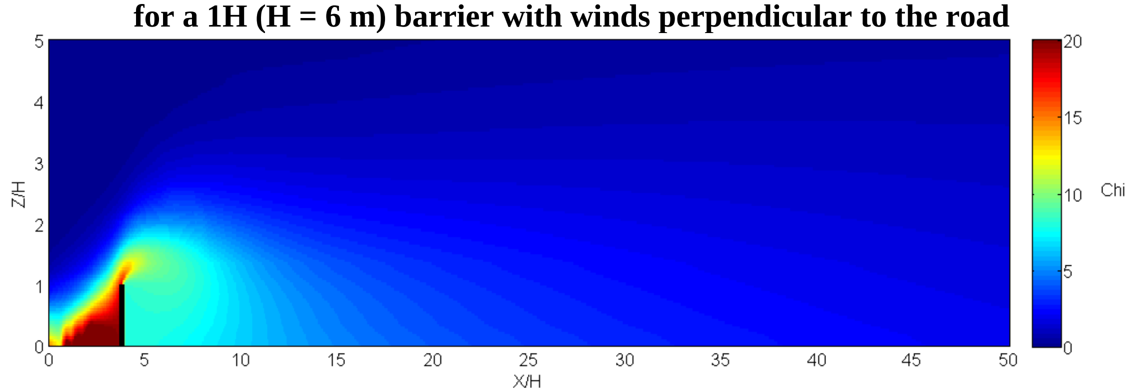
Field measurements were conducted at three locations in North Carolina – a vegetative barrier site along NC 15-501 in Chapel Hill, a vegetative barrier site along I-85/I-40 in Mebane, and a brick noise barrier site along I-440 in Raleigh (Figure 3). Sampling was conducted onboard three mobile monitoring vehicles equipped with air monitoring instrumentation. Two vehicles remained stationary, one positioned behind the barrier and sampling at two heights (3 m, 7 m) and the second positioned at an equal distance from the highway in a clearing and sampling at one height (3 m). Measurements at the fixed locations included carbon monoxide, ultrafine and accumulation-mode particle counts, and 3D wind speed and direction. A third all-electric vehicle measured particle counts (ultrafine, fine, and coarse) and black carbon while driving a route that included the highway and near-road areas with and without barriers present. Sampling was conducted during morning rush hour (7:00-9:00 local time) for 10 consecutive weekdays at each single location, with the vegetative barrier sites revisited in the winter to observe the influence of decreased leaf density. During each field campaign, the road side barrier was documented in terms of physical dimensions and measured for LAI.

Figure 3. Field sites in Chapel Hill (left), Mebane (middle), and Raleigh (right)

Results and Discussion

Preliminary field, wind tunnel experiment, and model results generally all indicate that ground-level concentrations are lower behind barriers, relative to a no-barrier situation, when directly downwind of a roadway. An example of CFD modeling results (Chi, model-normalized concentrations) for a 6 m solid barrier illustrates how the barrier reduces the horizontal dispersion and increases the extent of vertical dispersion of an inert tracer of roadway emissions.

Figure 4. CFD model results showing downwind normalized concentrations (Chi) for a 1H (H = 6 m) barrier with winds perpendicular to the road



In addition, wind tunnel investigations studying vegetative barrier effects demonstrate that porous vegetation may reduce near-road particulate concentrations. For example, wind tunnel data SMPS/CPC results for the broad leaf barrier case at 1 m/s air flow reveal average reduction of 27% over the size range of 0.04-0.23 µm particles. This data should be interpreted as a case where air flow is forced through the vegetation, thus the concentration reductions are expected to be due to collection by leaf surfaces and not by altered plume dispersion. In reality, a vegetative barrier located adjacent to a roadway affects near-road air quality through a combination of both collection by leaf surfaces (i.e. deposition) as shown in the wind tunnel and altered dispersion patterns as shown in CFD modeling simulations.

SUMMARY

A combination of field monitoring, wind tunnel experiments, and CFD modeling has been conducted by EPA in order to understand the potential of roadside barriers to mitigate the local air quality impact from traffic emissions. Preliminary data show that ground level near-road air quality is expected to be improved under the specific condition of winds perpendicular to the roadway, which is in agreement with past research.[1-3] In addition, initial wind tunnel results confirm that vegetative barriers likely affect near-road concentrations through both particle collection by leaf or needle surfaces as well as by altering traffic emissions dispersion patterns. A range of other conditions, such as variable wind direction, are also under investigation for field data and CFD modeling. This research will ideally support improvements in near-road air quality modeling and road design.

DISCLAIMER

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