INFLUENCE OF ROADSIDE VEGETATION BARRIERS ON CONCENTRATIONS OF TRAFFIC-SPEWED ULTRAFINE PARTICLES

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Abstract: The study of ultrafine particles (those below 100 nm in diameter) is of great interest to the scientific community and policy makers due to their likely impacts on human health and the environment. Understanding the behaviour of ultrafine particles from their number concentrations and size distribution point of view in the ambient air will help to expedite the development of regulatory controls. Vegetation barriers are used in many places to reduce the pollution generated by the road traffic from reaching to the people living in urban areas, especially close to the road, where the ultrafine particles are expected to be in high concentrations. Limited information currently exist that could reveal detailed understanding about the effectiveness of near road vegetation barriers in removing concentrations of ultrafine particles. A fast response differential mobility spectrometer (DMS50) is used for the pseudo-simultaneous measurements of number and size distributions in the 5-560 nm size range. The measurements were made at four different points along the side of a busy highway. These points were at the front, middle and back of the vegetation barrier, and at a point without any vegetation; all these points were at the same height above the road level. The data was collected at 10 Hz sampling rate, with $T_{10\text{-}90\%}$ equal to 500 milliseconds, during a weekday (7 August 2012) and a weekend (11 August 2012). Analysis of the data was performed to investigate the influence of near road vegetative barriers on the number concentration and size distributions. Further analysis will be carried out to develop understanding about the effect of wind direction on the efficiency of the vegetation barrier and an indication about the dispersion of particles as they move away from source (vehicle tailpipe) through the vegetation barriers to roadside footpath. Preliminary results based on the weekday data shows that the concentrations of particles gradually decrease while passing through the vegetation barrier. No clear trend was found from the weekend data due to winds being parallel to road and low traffic density. Detailed analysis of the data is currently underway.

Key words: *Experimental investigation; Ultrafine particle; Vegetation barrier; Near-road; Traffic emissions.*

INTRODUCTION

The available research has demonstrated an association between the ultrafine particles and various adverse effects on the human health (Bakand et al., 2012; Heal et al., 2012) and the environment (Stjern et al., 2011). These negative impacts motivate the control of ultrafine particles as they have an influence on our quality of life and contribute to notable mortalities as a consequence of their exposure in higher quantities (Kumar et al., 2011, 2013). In many counties, vegetation barriers are used to reduce the pollution generated by road traffic from reaching to the surrounding population. It has been suggested that road design (Baldauf et al., 2008; Cahill, 2010) and road barriers (Finn et al., 2010; Heist et al., 2009) have a positive effect on improving the air quality near roads. Emissions from vehicles are clearly considered to be a dominant source of particle number concentrations (PNCs) in the nanosize range (Kumar et al., 2010; Morawska et al., 2008). Therefore, the need to understand the influence of vegetative barriers near the road is essential to mitigate the nanoparticulate pollution.

Effects of vegetative barriers on particle number distributions (PNDs) were recently tested near roadside in North Carolina with a comparison between model and field results (Steffens et al., 2012). The study revealed that PNCs for particles over 50 nm, displayed generally suitable compliance with the model used. However, the model over predict the particles below 50 nm in diameter behind the vegetation barrier. A further non-linear reduction in PNC was found to correspond with an increase in leaf area density and this effect varies between different sizes. Pine and juniper branches were studied experimentally and theoretically for the collection efficiency of ultrafine particles in another study (Lin et al., 2012). This study found that the wind tunnel measurements obtained and the proposed analytical model, even with the incorporation of several simplifications, showed correlation to within 20%.

Hwang et al. (2011) conducted an experiment to test the particle removal by different kinds of tree leaves in a deposition chamber for particles in the size ranges below 1000 nm and 100 nm. The study recommends that leaf surface roughness is an important parameter for fine particles removal along with the shape of the tree leaves. A recent wind tunnel experiment was conducted in USA to study the ability of branches of two evergreen species to remove ultrafine particles (Lin and Khlystov, 2011). The study found that the smaller the particle size, the higher is the corresponding efficiency of removal. It is also found that the removal efficiency fell with corresponding decreases in packing density and increases in air velocity and it is independent of the branch orientation. The deposition of the smallest particles is controlled by Brownian diffusion, while the interception and inertial impaction determine the deposition of larger particles (Petroff et al., 2008).

Hagler et al. (2012) investigated the impact of structural and vegetative barrier at two near road sites in North Carolina, USA, on ultrafine particle concentrations with different wind conditions. The study reported that variable trends in PNCs were noted at different sites due to their removal from vegetative barrier. In some cases worst results were reported behind the vegetative barrier, which allows traffic-related air pollution access through the barriers in higher concentration to near-road areas. Wania et al. (2012) modelled the street canyon vegetation to investigate the particle dispersion. The study showed an increase in PNCs and a consequent loss of canyon ventilation was found to be due to the reduction in wind speed from the presence of vegetation in the canyon. Ries and Eichhorn (2001) reported similar findings, which are within the vegetated street canyon. For instance, a slight increase in pollutant concentrations was found to be corresponding with a reduction in wind speed, this may be the reason to avoid the dense vegetation in street canyon.

The main purpose of this study is to investigate the influence of near road vegetative barriers on the PNCs and PNDs in the range of 5-560 nm and a fast response differential mobility spectrometer (DMS50) was used to carry out the measurements. For better understanding, four different locations having the same vertical height were selected. The two of these locations were at the both sides of the vegetation barrier, the third one in middle of the barrier and the fourth one at a place without any vegetation. This was to develop an understanding about the effect of wind direction on the efficiency of the vegetation barrier and to see the dispersion of particles as they move away from source (vehicle tailpipe) through the vegetation barriers to roadside footpaths.

DATA COLLECTION

Site description

The experiment site is a small section of the A3 highway connecting Guilford town to London and Portsmouth, UK. The highway is comprised of six traffic lanes, with 3 lanes carrying the traffic in each direction. The site is located at the west end of the University of Surrey behind the Guildford School of Acting. The geographic coordinates of the experiment site is approximately +51° 14' 37.08"N, +0° 35' 47.00"W. During the measurements periods, metrological data was collected from the Wisely weather station. The metrological conditions are summarised in Table 1.

Table 1: Metrological conditions from the Wisely weather station for the experimental period.

Date	Time	Mean wind speed (m s^{-1})	Wind direction (^{o})	Mean temperature (^{o}C)	Mean relative humidity (%)
07/08/2012	16:23-18:33	2.57	230-250	16	84.5
11/08/2012	12:59-14:44	3.08	100-120	23.3	44.6

Instrumentation and data acquisition

The experimental setup of this study is presented in Figure 1. DMS50 was used to measure PNCs and PNDs for particles in the range of 5-560 nm at a 10 Hz sampling rate, with $T_{10\text{-}90\%}$ equal to 500 milliseconds. This measurement provides near real-time continuous measurements. For the quality assurance, the DMS50 was calibrated by the manufacturer on January 2012. The DMS50 was set to average the 10 samples (i.e. 1 s sampling rate) to improve the signal-to-noise ratio for attaining a high quality data and to reduce the data for proper handling. The DC powered solenoid switching system was designed to collect data from various locations (4 locations in each cycle) at desired timing. To obtain a representative data at each location, the measurements were taken simultaneously every one second at each sampling point for a period of 20 seconds. Sampling locations were at front (L2) and back (L4) of the barrier, middle of the barrier (L3) and without any vegetation in a section where road has vegetative barriers before and after sampling position (L1). All the points have same vertical distance from the road surface. All instruments mentioned in this paragraph were operated by three 12 V leisure batteries.

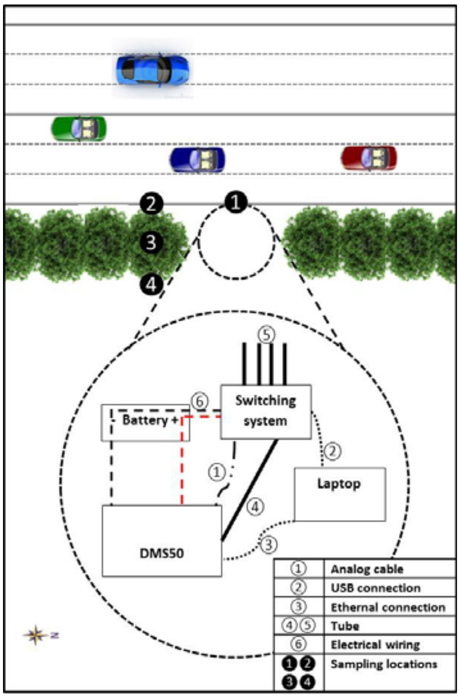

Figure 1: Schematic diagram of the sampling site showing the sampling points and experiment setups as described in the text. Please note that the figure is not in scale.

A total of 163 measurements cycles consisting of 2308 valid measurements of PNCs and PNDs were undertaken intermittently on 7 August 2012 (weekday) from 16:23-18:33 and on 11 August 2012 (weekend) from 12:59-14:44. The reasons behind selecting these intermittent timings are the experimental limitations such as the lack of continuous power supply and the absence of secure place. The objective of this article is to compare the relative measurements taken at different sampling points to analyse the effects of vegetation on reduction in PNCs. Therefore, the particles lost in the sampling tubes are not corrected in this analysis here.

RESULTS AND DISCUSSION

An initial analysis of the PNCs and PNDs measured data that is collected at near road location is illustrated below. This collected data is part of a bigger experimental research programme, which is currently under progress.

The closeness of the sampling instrument to the road and due to the traffic generated turbulence, the particles were expected to reach to the inlet of the DMS50. On both sampling periods, the data for locations L2, L3 and L4 shows that the total PNCs gradually decrease with increasing distance while passing through the vegetation barrier. This could be attributed to the effect of dilution and/or deposition of particles from the presence of vegetation barrier. As expected, the total PNCs at all locations were found to be greater during the weekday measurements compared with those measured at the weekend because of the high traffic density. For instance, on the weekday, the total uncorrected PNCs measured at L2 were 1.70×10^{5} cm^{-3} which were reduced by 14.1% at L3 and 3.6 % at L4. This clear PNCs reduction in weekday was enhanced by the winds being perpendicular to road and high traffic density. In weekend, the total PNCs at locations L3 and L4 were approximately two-fold lower than those measured at L2 as it is closer to the road; no clear justification for this variation was found.

As seen in Figure 2a, PNDs remains consistent and its number concentration dropped with increasing distance from the edge of the highway through the vegetation barrier when the wind was blowing across the road. The PND on each sampling location displayed a clear tri-modal PNDs with modes at around <6, 10 and 75 nm. Similar peaks were exhibited at around 15 nm and 87 nm while measuring ambient ultrafine particles in urban street canyon (Kumar et al., 2008). At L2, this highest mode occurred at around 6 nm with PND of 2.2×10^5 cm^{-3}. At all the sampling locations, these distinct modes occurred approximately at the same diameter which may be explained by the short distance between the sampling locations. Both modes at <6 nm and 10 nm are attributed to the formation of the new nuclei (fresh nuclei), which were attributed to the particles formed by nucleation either from the unburned organic fraction from the engine tailpipe and/or background gaseous precursors. In this situation, the nucleation of the engine tailpipe materials is more likely to be the reason because of the measurement device was very close to the road. Particles less than 10 nm were shown to be generated from both diesel and petrol fuelled vehicles (Shi et al., 2001). Morawska et al. (2008) has addressed that particles in the size ranges of 20-60 nm and 20-130 nm were attributed to the emissions from petrol and diesel engines, respectively. The mode at 75 nm is ascribed to particles formed directly in the combustion chamber (or shortly thereafter) by the condensation of volatile material onto this pre-existing carbonaceous spheres, or coagulation of smaller mode particles (Kumar et al., 2010; Schneider et al., 2005). Charron and Harrison (2003) has linked the particles with diameter greater than 60 nm with the heavy-duty vehicles (diesel vehicles). As presented in Figure 2b, weekend PNDs for L1 and L2 are reasonably close to each other and most of the effect are from the sweeping of particles along the road because of the parallel wind to the road and in this case the vegetation are not acting sufficiently. L3 and L4 are experiencing more similarity in their PNDs than L1 and L2; this could be attributed to their locations being situated farther than L1 and L2.

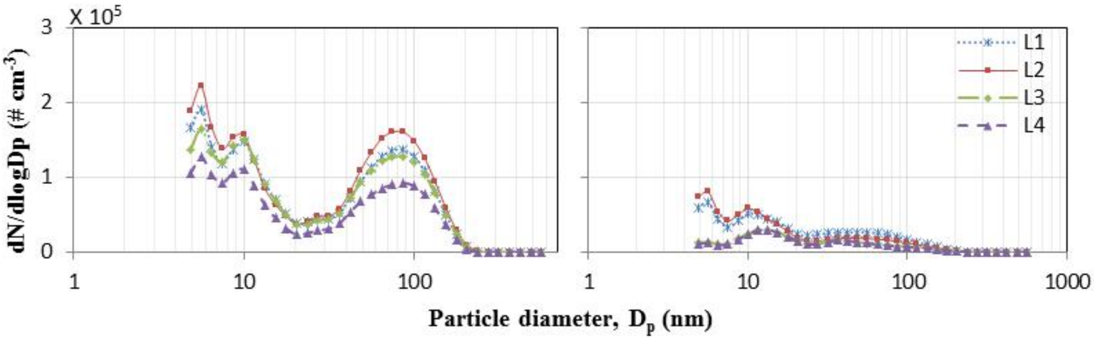

Figure 2: Particle size distribution at various sampling points on (a) 7 August 2012 (weekday) (b) 11 August 2012 (weekend).

SUMMARY AND CONCLUSIONS

Preliminary results shows that the total PNCs gradually decrease with increasing distance while passing through the vegetation barrier, especially when the wind was blowing perpendicular to the road. The PND on each sampling location displayed a clear tri-modal PNDs with modes at around <6, 10 and 75 nm. These modes persisted at all locations without shifting to larger size. The differences in PNCs and PNDs measured during the weekdays and weekend measurements can be adequately explained by the different traffic density and weather conditions, especially the wind direction. Limited data is currently analysed to come up with sensible conclusion regarding the effectiveness of near road vegetation barriers in removing concentrations of ultrafine particles. Further measurements and detailed analysis of the data is currently underway that may lead to variation in the values presented here.

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