HORIZONTAL DISTRIBUTION OF SUBMICROMETRE PARTICLES FROM VEHICLE EMISSIONS NEAR A MAJOR ROAD: IMPLICATION FOR BUILDING LOCATION

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ABSTRACT

Particle characteristics in indoor environments are strongly related to the characteristics of outdoor particles. The aim of this work was to investigate how submicrometre particle number concentration changes with the distance from a road. This information is necessary for choosing the optimal ventilation and filtration systems of buildings, to better protect the occupants.

This work involved measurements of the total number concentration of submicrometre particles from vehicle emissions, at increasing distances from a major road, using a TSI Scanning Mobility Particle Sizer in the size range 0.015 – 0.697μm.

The measurements conducted at distances from the road ranging from 15 to 375m showed, that for conditions where the wind is blowing directly from the road, the concentration of fine and ultrafine particles decays to around half of the maximum (measured at the closest point to the road) at a distance of approximately 100 - 150m from the road. For the wind blowing parallel to the road, the reduction to half of the concentration occurs at 50 – 100m. There is no effect on total particle number concentration at a distance greater than 15m from the road, when the wind is blowing towards the road and away from the sampling points.

KEYWORDS: Outdoor air, exhaust emissions, particles

INTRODUCTION

In an urban environment, motor vehicles are often the most significant pollution source, seriously affecting outdoor air quality and ultimately indoor air quality as well. Out of all the contaminants emitted by the vehicles, particulate matter, especially in the very fine range, could have the most significant health effects.

Throughout the last thirty years, there have been a number of scientific studies indicating that particulate air pollution can have an acute effect on human health, [1]. Standards for monitoring the mass of particulate matter less than 10 μm (PM_{10}, - coarse particles), and less than 2.5 μm ($PM_{2.5}$, - fine particles) have been established in a number of countries. A major contributor to urban pollution however, is vehicle emissions, which may not be represented in PM_{10} or $PM_{2.5}$ measurements due to its nanometre size particles.

A number of studies have examined the dispersion of pollutants with distance from a source. One study modelled the dispersion of NO, NO_2, CO, and O_3 concentrations while measuring the concentrations at three distances from the motorway (50, 100, and 600m), [2]. The model predicted gas levels to decrease (except for ozone) over the 600m, which was confirmed by the data measured at 100m and at 600m. There were no measurements of particulate matter.

Suspended particulate matter, NO and NO_2 were measured at different distances from a major road in Tokyo, [3]. There was a decreasing gradient with increasing distance for all measurements out to 150m.

Another study examined PM_{10}, $PM_{2.5}$, black smoke, and benzene at four different distances from a major motorway [4]. In this study, monitoring sites were set up at approximately 50, 100, 150, and 300m from a major motorway at two different locations. It was concluded that NO_2 and black smoke concentrations decrease with increased distance from a road, whereas there is no significant decrease in concentrations of PM_{10}, $PM_{2.5}$, and benzene.

The mass concentration and elemental composition have been compared for particulate sampled near major roads and at background locations, [5]. It was concluded that PM_{10} and $PM_{2.5}$ concentrations were on average 1.3 times higher near the road compared with the background readings, and black smoke (elemental carbon) readings were 2.6 times higher. Interestingly, the levels of Fe and Si were significantly higher in PM_{10}, and to a lesser extent in $PM_{2.5}$, samples near the road, indicating a contribution from suspended road dust ie. vehicle exhaust emissions may not be the only source for PM_{10} and $PM_{2.5}$ when measuring close to a busy road.

Another study evaluated the PM_{10} emission rates from paved and unpaved roads out to distances of approximately 80m using the tracer gas SF_6, [6]. The assumption was that SF_6 simulates particulate matter transport for the distances used in the experiment. There was a clear decreasing trend for concentrations of SF_6 as distance increased.

Horizontal and vertical profiles of submicrometre particulates in relation to a busy arterial road were examined by Morawska, *et al*, 1999 [7]. The study selected two sites within the city area of Brisbane, one at a distance from the freeway of up to 210m, and the other located at the junction of several major transport routes in the central business district (distance from freeway up to 73m). There was no significant decrease in particle number concentration with distance from the road for the first site, but there was a decrease in concentration at the second site. This difference was thought to be due to the topography at the sites. Further investigation into a more open topography was necessary.

The focus of the present work was to examine the change of the total number concentration of particles of size 0.015 – 0.697μm, from vehicle emissions, at increasing distances from a major road. When combined with outdoor to indoor penetration data, exposure to outdoor particles within a building can be determined. This can ultimately be used to improve ventilation and filtration systems to provide safer indoor environments.

Previous major studies at the Environmental Aerosol Laboratory (EAL) of the Queensland University of Technology (QUT), focused on direct vehicle emissions and included comprehensive examination of the gaseous and particle phases of city council bus exhaust (diesel fuel), [8], and of car exhaust (petrol and LPG fuel), [9]. These studies presented information on the concentration and size distributions of particles in the exhausts of both cars and buses for different load and speed conditions for the test fuel used in the measurements. The majority of particles from the exhaust were found to be in the range 0.02-0.13μm (diesel) and 0.04-0.06μm (petrol). Thus the lower particle size range chosen for the measurements presented here ensures that most of the particles which are directly related to motor vehicle emissions are detected.

METHODS

Measurements of particle number concentration in the range from 0.015 – 0.697μm were taken using a TSI Model 3934 Scanning Mobility Particle Sizer, at increasing distances from a major road. Measurements were made under different wind conditions, while temperature and relative humidity were recorded.

The site selected was in Brisbane, beside the Gateway Motorway at Tingalpa, a major Brisbane bypass road. It consisted of a small bitumen road running perpendicular to the motorway, providing access to parklands. This small road had a negligible amount of traffic (an estimated one car per hour) and was below the level of the motorway by approximately 3m. The terrain at the site was flat, with an unobstructed view to the major road.

The traffic flow on the motorway was estimated by counting the numbers of cars, light trucks, and heavy trucks passing by in random 5min periods during the measurements. The average traffic count during all measurements was 3400 vehicles per hour.

Measurements were made under three wind conditions:

a) wind blowing directly from the source towards the sampling points, (within a 45° arc of the normal to the road),
b) wind blowing away from the sampling points, towards the road, (within a 45° arc of the normal to the road), and
c) wind blowing parallel to the road, (within a 45° arc of a line parallel to the road).

Samples were taken at intervals of 40m, starting at 15m from the source as the closest point, and ending at 375m. To minimise the effect of fluctuations in the source with time, the closest point to the source was used as a reference point. Samples were taken alternately from this point and from each of the more distant points ie. every second measurement was taken from the reference point.

All measurements were taken from the instrumentation inside the EAL vehicle with sampling tubes extended vertically from the window. Measurements of temperature and relative humidity were taken outside throughout the measurement period. The weather station was erected approximately 30m from the motorway and recorded wind speed and direction continuously at 6min intervals. In total, sampling time at each point lasted 15mins, and approximately 4h was required for one complete set of measurements (sampling at all distances) at the site.

RESULTS

Wind from the road towards the sampling points

Figure 1 shows the resulting normalised concentrations for the cases where the wind was blowing from the road towards the sampling points. Concentrations were normalised by finding the ratio of a concentration at a particular distance and it's corresponding concentration at 15m. The average value of all concentrations at 15m was then used to normalise these ratios, and the concentrations at each distance were recalculated. The error bars are standard errors calculated from the standard deviation of five samples at each point. Figure 1 shows a significant decrease in the total number concentration of particles smaller than 0.7μm as the distance from the road increases. At a distance of around 150m, the concentration decays to around 50% of the maximum occurring at 15m from the road (the closest measurement point to the road). Concentrations close to the road are higher for the lower wind speeds and lower for the higher wind speeds. This is due to greater dilution at higher wind speeds.

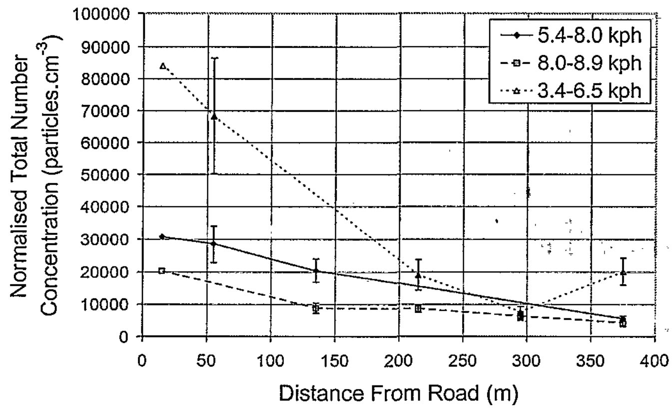

Figure 1. Horizontal concentration profiles of submicrometre particles from vehicle emissions. Wind blowing from the road towards the sampling points.

Wind parallel to the road

Figure 2 presents data for the situations where the wind was blowing parallel to the direction of the road. The total particle number concentration decreases significantly with distance from the road, and approximately half of the maximum concentration levels are reached at around 50 to 100m. Again, the higher wind speeds give a considerably lower total number concentration.

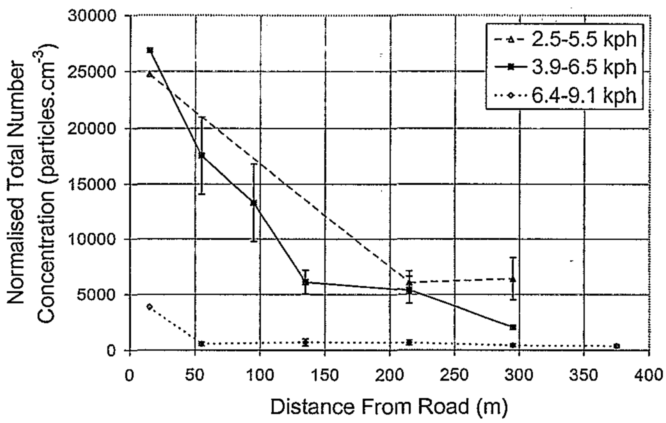

Figure 2. Horizontal concentration profiles of submicrometre particles from vehicle emissions. Wind blowing parallel to the road.

Figure 3 shows data for the situations where the wind was blowing towards the road, and away from the sampling points. There is no trend in this data and the total particle number concentration is similar to the average urban values measured at the Air Monitoring Research Station (AMRS) at QUT.

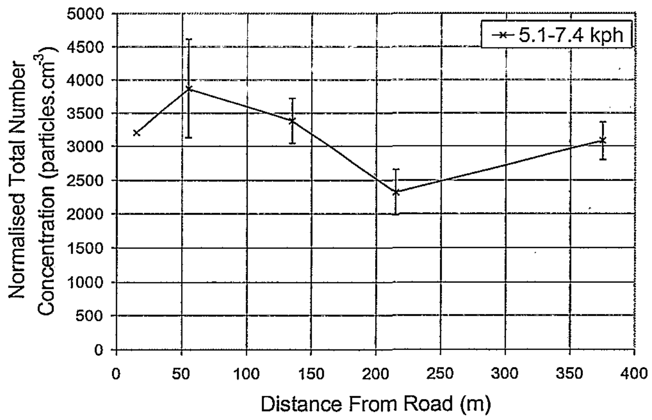

Figure 3. Horizontal concentration profiles of submicrometre particles from vehicle emissions. Wind blowing towards the road, away the sampling points.

DISCUSSION

The horizontal distributions of particles from vehicle emissions near a major road were investigated and total number concentrations of particles were measured for three wind directions in relation to the road. There is a clear decrease in submicrometre particle number concentration (in the range 0.015 – 0.697μm) from vehicle emissions, as distance from the road increases. For conditions where the wind is blowing directly from the road, the concentration decays to about half that of the maximum occurring at 15m from the road (the nearest measuring point from the road), at a distance of approximately 100 - 150m from the road. This reduces to 50 – 100m for wind blowing parallel to the road. There is no effect on total particle number concentration at distances greater than 15m from the road when the wind is blowing towards the road and away from the sampling points.

From the findings of this study it is clear that exposure to submicrometre particles is significantly increased within the distance from 15 to 150 –200m from a major road, compared to the urban average exposure levels (up to approximately seven times higher). The implication on exposure control is thus either avoidance of construction of buildings within this distance from the road, or, as this may not be practical for many urban developments, installation of appropriate filtration systems such as electrostatic filters, which have a high performance for submicrometre particles. Control of exposure by increased filtration capability of the filtration systems, is a solution which applies only to the buildings whose occupants spend the entire time indoors, and not outside the buildings. It does not apply to facilities such as schools, childcare centres, or retirement villages, whose users or occupants could spend a significant fraction of time outside the buildings. In the case of such facilities, an increased distance from a major road is the most significant solution for exposure control.

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