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Local Aspects of Vehicular Pollution

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Abstract

We consider the local aspects of vehicular pollution by wind tunnel testing used in conjunction with a tracer-gas technique. These initial results show that the level of pollution received by a commuter in slow-moving heavy traffic may be as much a function of the pollution produced from the car in front as other environmental aspects.

Introduction

Air pollution from vehicles is of increasing concern, and the issue is of prime importance in many cities in the U.K. and the rest of the developed world. The health aspects of pollution are not yet fully understood, but the increase in asthma, other respiratory diseases and certain types of cancer are being linked to pollutants emitted from vehicles such as carbon monoxide, oxides of nitrogen, and volatile organic compounds[1]. Consequently it is of great importance to measure an individual's exposure to these pollutants in the course of their daily activities, both in the workplace, and whilst commuting to and from work[2-5]. Studies have shown that levels of pollution experienced whilst commuting by road to and from the workplace are much higher than those experienced at work or at home, and an individual receives most of his daily dose of pollution whilst commuting[6]. Hence these levels, and the resulting dose of pollution should be closely monitored. Several methods have been developed which detect the concentration of various pollutants at the roadside[7-8], but the levels of pollutants inside a vehicle are generally greater than these roadside measurements[1]. There may be for several reasons for this. The level of pollution decays away from the source, and consequently the levels around the vehicles in traffic will be higher than the levels at the roadside. This makes careful location of monitoring equipment essential. Secondly, the method of ventilation used by individual vehicles may serve to concentrate the levels of pollutants inside the vehicle if the air conditioning and state of windows, sun roof etc. is not effective, or conversely an efficient ventilation system may reduce the levels[9]. Conflicting reports exist as to whether it is better to drive with the windows open or closed in heavy traffic[10-11]. The air space inside a vehicle can act as a buffer against sudden high levels of pollution, but this would also slow the beneficial effect of driving from an area with a high level of pollution into an area with a lower level[6]. Simplified models assuming complete mixing inside the vehicle have been proposed to measure this buffer effect[12-13], but the assumption of complete mixing is far from true in a real situation where the air flow inside a vehicle may produce highly localised concentrations of pollutants.

An alternative approach is to measure pollutant concentration inside a vehicle while driving in traffic. Several techniques are available, either using a mobile gas sensor[1,10-11], or collecting samples of vehicular air for subsequent analysis[7,10]. The mobile gas detector method has the advantage of not only giving the total pollution dose, but also the pollutant concentrations at various landmarks which can be compared with climate, traffic density, queuing time at junctions, and so on. However, it may be necessary to collect gas samples or to use some other total exposure method to detect volatile organic compounds. Several studies have been carried out along these lines[12,14-16], but the findings are only of direct relevance to the route and vehicle used in the study. Little information is produced that can be applied to other routes in the same city, or used to predict the pollutant exposure of commuters in other cities using different vehicles with different ventilation characteristics. The local nature of the problem was shown by Colwill and Hickman in an early study which considered the levels of pollution in several types of vehicle driven along the same route[11]. The levels varied considerably from vehicle to vehicle, underlining the role of an effective ventilation system in reducing commuter's exposure to pollution. Clearly a more fundamental approach is needed if general statements are to be made about the exposure of commuters to pollutants.

Important aspects ignored by the studies already mentioned are that pollution from a vehicle is produced at a specific location, and there may be significant local effects in the concentration of pollutants around traffic. Most pollution emitted from a vehicle comes from the exhaust. Given that the levels of pollution are highest in slow moving traffic, on calm days, especially when approaching or accelerating away from road junctions, it is necessary to consider the dispersion of the pollution produced at the exhaust by the wind, and the air flow around the adjacent vehicles. The hypothesis here is that the levels of pollution in a vehicle may be strongly influenced by the levels of pollution produced from the exhaust of the vehicle immediately in front. Whilst this theory falls down at high speed with strong cross winds, at low speed, and on calm days, i.e. the worst case, it seems more plausible. The experimental observations of Chaney bear this out[17]. He drove at a constant speed of 52 m.p.h. along a highway and monitored the level of carbon monoxide as various vehicles overtook his vehicle and pulled into his lane about 50 ft ahead. At the differential speed from 3 to 10 m.p.h. he noticed significant peaks in the level of carbon monoxide that were directly attributable to the vehicle in front. Clearly driving behind such a vehicle for a significant time in slow moving traffic would have an effect on the level of pollution inside a vehicle.

Such observations have prompted the current work which is concerned with modelling the dispersion of pollutants around three simplified vehicle shapes. Wind tunnel testing has been used to examine the theory that the pollution to which a driver is exposed may be a local phenomena, and in future this will be followed up with experimental observations in traffic and computational fluid dynamics, which is the subject of current research.

Wind Tunnel Testing

Low Velocity Atmospheric Wind Tunnel

The tunnel used for this series of tests was based on a small open-jet wind tunnel developed for teaching purposes by the Building Research Establishment. This tunnel has a maximum flow rate of 4.5m/s and a working section of 1.0m wide by 0.75m high and 2.25m long. Two layers of honeycomb are fitted in the bellmouth to straighten the incoming flow, and are followed by a 0.5mm mesh screen. Beyond the entry section there is a 0.75m settling chamber to allow disturbances caused by the honeycomb and screen to decay, and to allow means to be introduced to modify the flow profile. A transformer is positioned between the working section and the fan to convert the 1.0m x 0.75m cross-section to a suitable shape for the fan mounting. The entry to the transformer is larger than the settling chamber exit to allow for some expansion of the flow through the working section. Fan speed is controlled using a variable auto-transformer which varies the voltage applied to the drive motor.

The tunnel was measured to determine any velocity variations across the tunnel section. Two sets of data were recorded; the first measured 0.5m downstream of the settling chamber, and the second a further 1m downstream. Only negligible velocity variations were found (±3%), although the turbulence intensity was higher at the second location. The flow through the tunnel was found to be stable up to 0.2m from the edge of the table.

Model Construction

Three hollow model cars based on the MIRA model were constructed from 10mm MDF at a scale of 1:10 (figure 1). The models were deliberately simple, and no attempt was made to model fine detail. Two of the cars were fitted with a single injection tube to simulate the engine exhaust which was positioned on the right hand side at the rear of the two vehicles. This was 1mm ID to allow simulation of the measured flow of exhaust from a car whilst the engine was idling (15-20 m/s). N_2O tracer gas was injected at a rate of 1 litre per minute and at 500,000 ppm to simulate the carbon monoxide concentration in a typical exhaust. The other model was fitted with several static pressure tappings to allow measurement of gas concentration and pressure around the body. These tappings were machined from 0.8 ID brass tubing, and fitted on all of the upper body surfaces. PVC tubing was attached to the tappings through a hole in the wind tunnel turntable to allow the tappings to be connected to the instrumentation.

Instrumentation

Twenty of the model pressure tappings were connected to a selection box. Gas analysis was carried out using a Binos 1000 gas analyzer. The instrumentation was connected to a Datron 1055 data logging system controlled by a portable P.C. (figure 2).

Model Arrangement

The three model cars were placed in line 20 cm apart to simulate a full scale gap of 2m (approximately half a car length). The car with the pressure tappings was placed at the end of the line. Initially the second car exhaust was switched on, and readings were taken from all of the pressure tappings on the third car with the wind tunnel speed set at 4m/s. Since the flow around the vehicles was turbulent, it was necessary to average the results over twenty seconds on each tapping. After the test had been completed, the second car exhaust was switched off, and the first car exhaust was switched on. Again readings were taken from all of the pressure tappings on the third car. Hence a picture of the proportion on pollution received from each of the first two vehicles by the third car was obtained.

Results

The results can be divided into two categories. Firstly, the data from the first test shows that there is considerable variation in the pollutant concentration over the surface of the third vehicle from the car immediately in front. The second test shows the relative proportion of pollution obtained from each of the two cars in front.

Test 1

The results from the first test show that, in general, the proportion of pollutant decreases along the length of the vehicle. This can be seen in figure 3 where the proportion of tracer gas is plotted for the pressure tappings along the centre-line of the vehicle. A sketch of the car is added to aid visualisation. From the figure it is evident that the pollution concentration is relatively constant across the bonnet, but falls sharply at the windscreen. The pollution is relatively constant along the roof, falls sharply again at the rear screen, and recovers slightly towards the rear of the vehicle. Table 1 shows the concentrations of the pollutant at the tappings along the sides of the vehicle.

Location	N_2O ppm Car 2
Left Headlamp	9.0
Left Vent	21.6

Left Window	9.3
Right Headlamp	71.5
Right Vent	58.6
Right Window	69.5
Right Side 1	123.5
Right Side 2	111.6
Right Side 3	90.7

Table 1: Pollution concentrations from car 2.

The results show that the highest concentrations occur along the right hand side as expected since these tappings are close to the exhaust, and in line with the dominant direction of the flow. However, there is a significant concentration at the left hand vent; the pollutant concentrations at the tappings along the left hand side were all less than 1 ppm. This is due to the flow from around the exhaust region travelling across the bonnet, and over the top of the car rather than around the side.

Test 2

Since the exhaust from the first car has further to travel before it reaches the third car the readings are lower due to the dissipative effects of the turbulent flow around the second car. This can be seen in figure 4 where the proportion of tracer gas is plotted for the pressure tappings along the centre-line of the vehicle. The concentration from the second car is also shown. From the figure it is evident that the pollutant concentration decreases slowly along most of the vehicle, but recovers slightly towards the rear. Thus it appears that the flow is well mixed due to the turbulence encountered. However, this is not the case across the whole surface of the car. Table 2 shows that there is still a significant concentration of the pollutant along the right hand side of the third vehicle, and at the right hand headlight, vent, and window.

Location	N_2O ppm Car 1
Left Headlamp	0.8
Left Vent	4.0
Left Window	0.3
Right Headlamp	16.7
Right Vent	14.5
Right Window	17.7
Right Side 1	24.9
Right Side 2	26.6
Right Side 3	25.4

Table 2: Pollution concentrations from car 1.

This may be due to a relatively laminar stream of air passing along the right hand side of the three cars, which would carry a significant amount of the exhaust produced by the first vehicle to the surface of the third car.

On average, where this effect occurs, the proportion of the pollutant from the first car to that of the second is about one quarter. This also appears to be the case for the well mixed stream of air down the centre-line of the cars.

Conclusions

These results represent a modest but valuable start in understanding the mechanisms involved in the transportation of pollutants around vehicles in slow moving traffic. Despite the crude nature of the wind tunnel model, the concentrations of tracer gas are of the same order as the carbon monoxide levels that drivers are typically exposed to, although no allowance has been made for cross-winds or for other environmental factors. These could be considered in future research. It has been shown that around 80% of the total amount of pollution received at the surface of a car may come from the car in front, and this has important consequences in shaping any future strategy to control the amount of pollution received by drivers.

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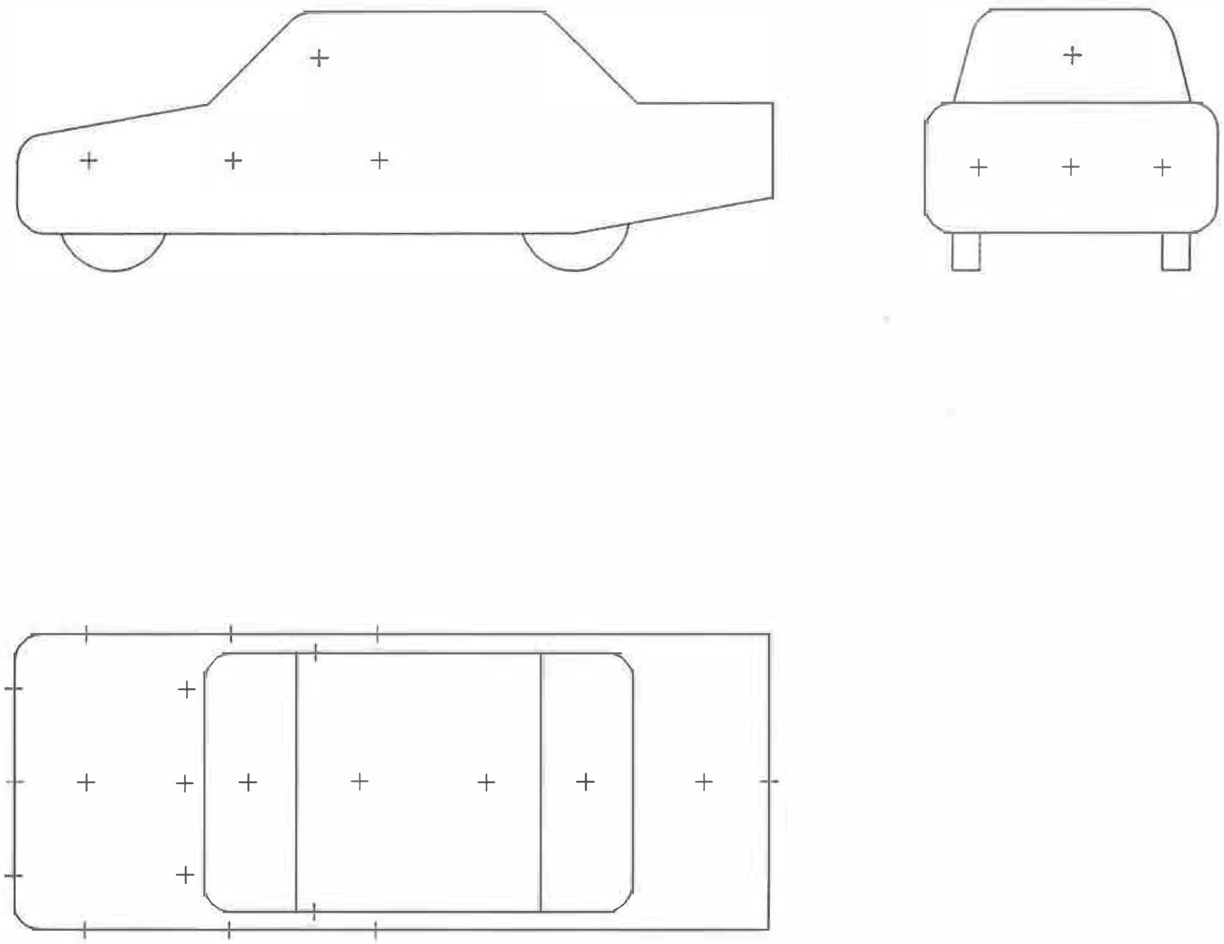
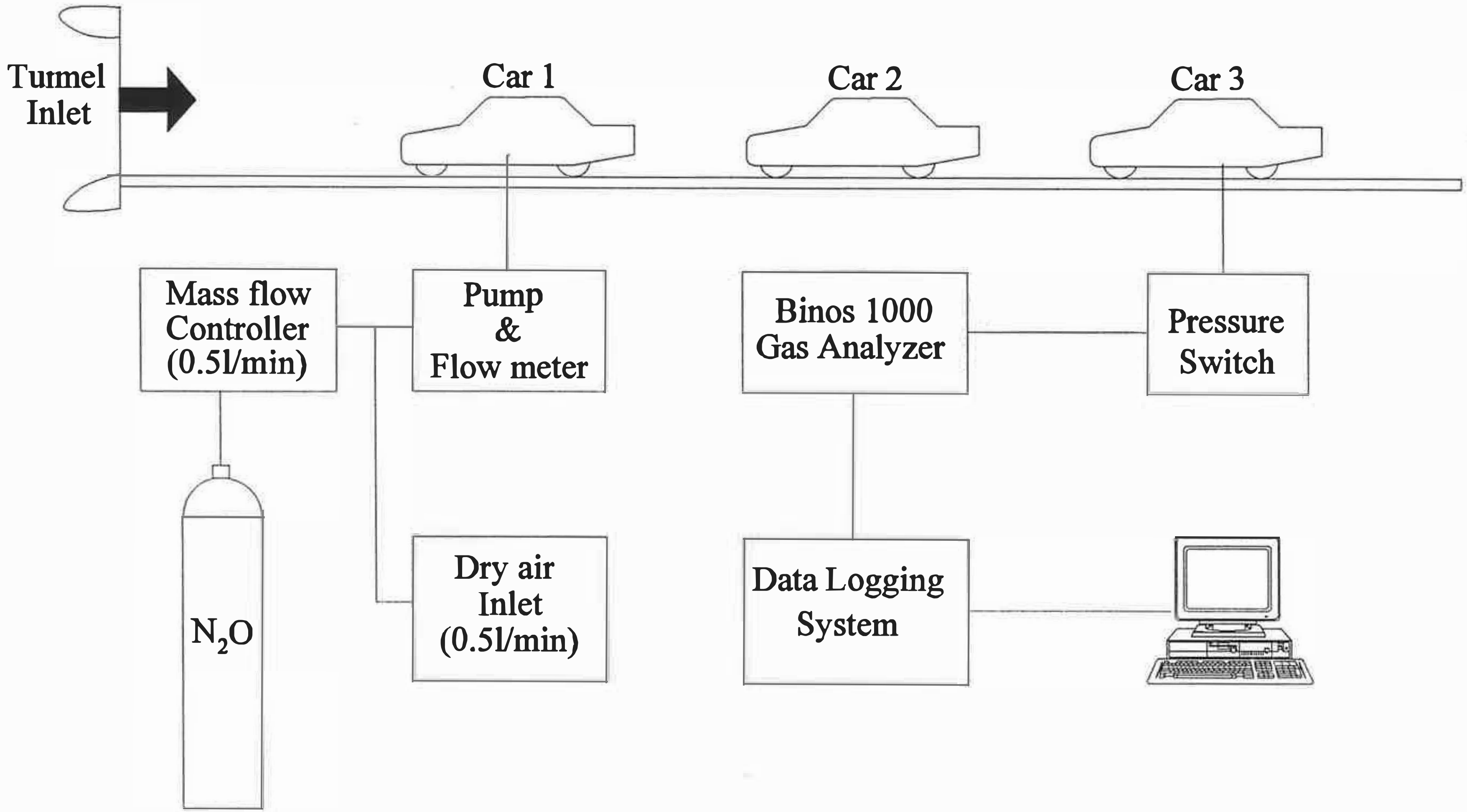


Figure 1: MIRA model with pressure tappings


Tunnel
Inlet
Car 1
Car 2
Car 3
Mass flow
Controller
(0.5l/min)
Pump
&
Flow meter
Binos 1000
Gas Analyzer
Pressure
Switch
N_2O
Dry air
Inlet
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Data Logging
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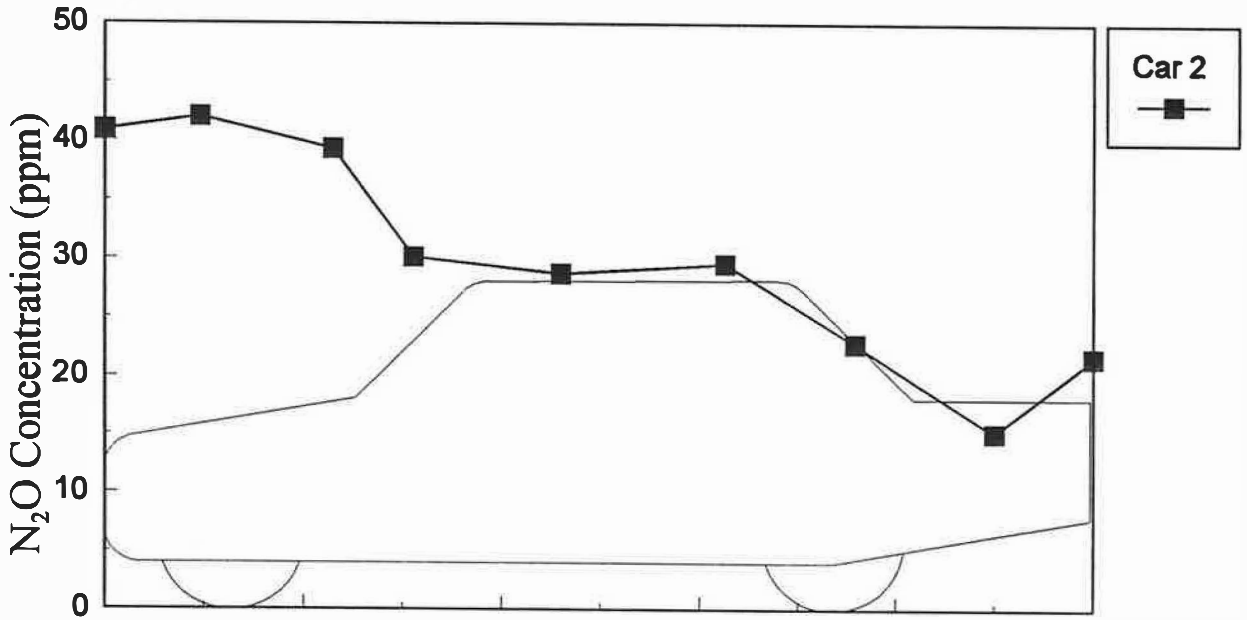
50
40
30
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10
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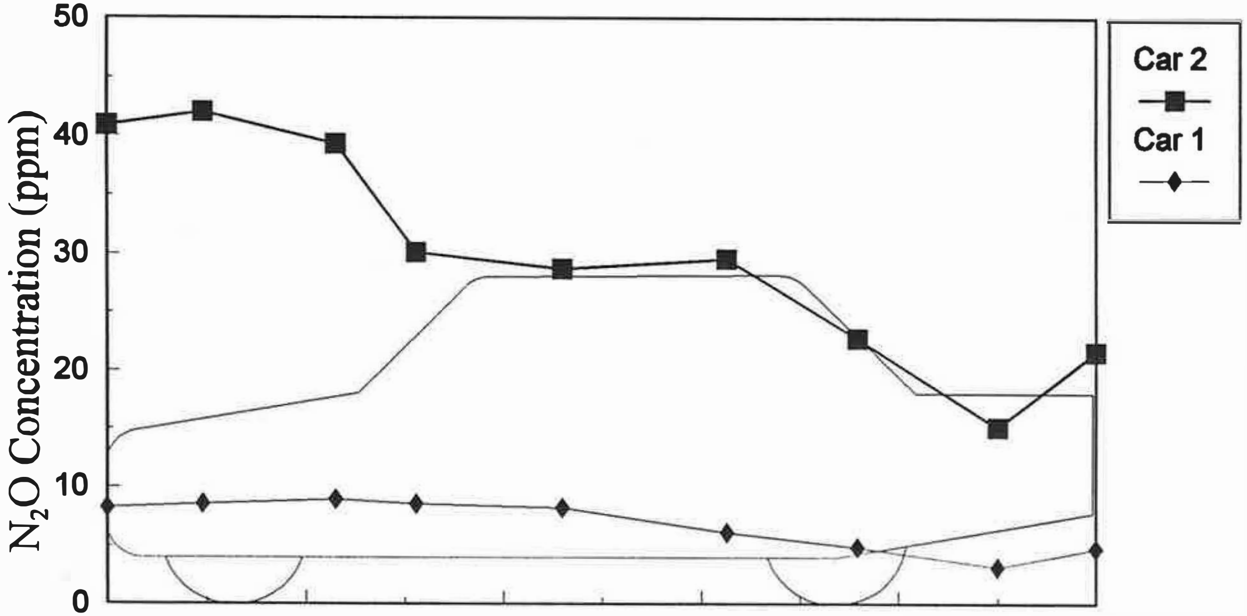
N2O Concentration (ppm)
Car 2



50
40
30
20
10
0
N2O Concentration (ppm)
Car 2
Car 1