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In-vehicle / Out-vehicle air quality and commuter's exposure to pollutants

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Carbon monoxide, carbon dioxide and nitrogen oxide concentrations were measured inside and outside of both a light-goods-vehicle and a bus at different driving conditions and routes using analysers and portable samplers. The study is to investigate the commuter's or passenger's exposure to both in-vehicle and out-vehicle pollutants during commutes. The main driving environments were selected: highway, countryside, and tunnel. The light-goods-vehicle was driven under three main types of ventilation conditions: air-conditioning with fresh air intake, air-conditioning with recirculation and natural ventilation. The bus, with both air-conditioned and those without, is driven along various urban bus routes and the number of passengers was recorded.

It is found that the IO ratio for the light-goods-vehicle is not specific only to the mode of ventilation but also to the driving environment. On the other hand, the IO values inside a bus seem to be less dependent on the outside driving conditions. It is found the exposure levels of carbon dioxides inside the air-conditioned vehicle is strongly dependent on the number of passengers. All these results call for further study of in-vehicle air-conditioning.

1. Introduction

We are all aware that vehicular exhausts contribute to a large portion of nitrogen oxides (NOx), suspended particulate matters and carbon oxides (COx) which have adverse health effects on human beings. There are reasons to believe the in-vehicle air as being unclean. For example most people like to close the windows to avoid directly breathing the polluted air. However air can infiltrate indoor through door seams, windows and so on. Air is also pumped into the car through the fan located at the bonnet, which is facing directly the exhaust pipe of the car in front. Thus the air that comes in through the air-conditioner cannot be considered clean. Moreover pollutants that infiltrated indoor might accumulate and lead to a surprisingly high concentration. It is thus of interest to study the pollution level inside a vehicle during commutes.

The present field study was undertaken to understand the various outdoor effects on the penetration of pollutants into a vehicle. We shall thus study the in-vehicle / out-vehicle air quality ratio (IO) of nitrogen oxides (NOx), carbon monoxide (CO) and carbon dioxide for a private and a public vehicle under different driving conditions and ventilation conditions. Different types of traffic environments in Hong Kong Island were selected: highway, country park, urban roads, and tunnel due to their different outdoor air and traffic density with three ventilation systems to be considered are natural ventilation (windows opened), air-conditioned (fresh air intake) and air-conditioned (air recirculated).

2. Methodology

2.1 Light good vehicle measurements

Sampling was carried out simultaneously inside and outside of a typical light-good-vehicle (Ford Econovan) during the winter season in Hong Kong. Monitor Labs 9841 NOx Chemiluminscent Analyzer was used to monitor the NOx concentration. The tubings are connected to the ambient environment through a well-sealed hole to perform the sampling while the indoor sampler is connected to the passenger compartment to measure its direct exposure. Measurements of CO are performed similarly using the portable IAQCALC carbon oxides sampler. Data were taken every three minutes to reduce the response time. Meteorological conditions and outdoor concentration data were acquired from the most nearby fixed stations for reference purpose. The driver of the vehicle kept travelling at normal speed without specific preference of lanes, which is indicative of real commuting situation. The test vehicle was also tested independently in a remote setting for pollutant intrusions and phase lag of equipment. More than 80 commuting trips were made during the entire measurement campaign, of which 70 of them provided quality data for analysis.

2.2 Bus measurements

Measurements were conducted during the the winter and spring season in Hong Kong. Samplings of both pollutants inside the bus were performed in the middle of the passenger compartment using the portable IAQCALC carbon oxides sampler. The measurement was made on an empty seat to avoid direct measurement of human's breath. Out-vehicle pollutants were measured by the same sampler located in a light-goods vehicle that followed closely the bus. Throughout the sampling, the time, the duration, the traffic conditions, the number of passengers and surrounding environments were recorded. Data were taken every two minutes to reduce the response time. Outside ambient conditions were recorded as in the light good vehicle measurements.

3. Results and discussions

3.1 Light good vehicle measurements

Figure 1 shows a typical indoor / outdoor variation of NOx and CO concentration. In this trip on a highway with air-recirculation mode, traffic congestion was experienced along the highway which was reflected by the high outdoor pollution level after the 12th minute of driving in all three measured pollutants. Despite this the variation of indoor NOx to this surge of pollution level was small. It can be seen that the concentration of NO_2 remained low inside the vehicle. On the other hand, the concentration level of indoor CO responded by increasing after a phase lag. It is interesting to note that the IO values of all three pollutants rose above one only after the traffic congestion, indicating a certain penetration time into the vehicle. Beside a small peak was observed for NO_2 at around the 8th minute, possibly suggesting pollutant buildup inside the vehicle due to air-recirculation. In fact as far as the IO was concerned, it was a local minimum during the time of traffic congestion. The comparatively high IO value for CO also suggested the possibility of a likely source of CO inside the vehicle.

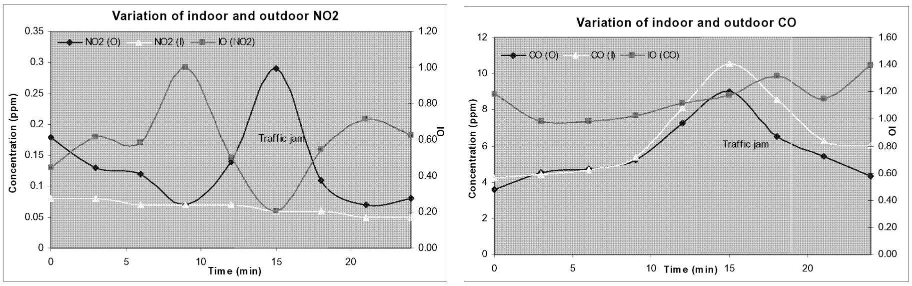


Figure 1: Variation of pollutant concentration and IO characteristics on a highway using air-recirculation for NO_2, and CO

A similar trip was made with the air-conditioning system was switched on but to 'Fresh-air' mode, where outdoor air is pumped continuously into the vehicle. Figure 2 shows that despite a minor difference in outdoor pollutant concentration, the trend for both indoor and outdoor pollutant concentration is actually quite similar. The IO value however shows a big difference with the previous case. There was a general drop of IO, thus confirming the dilution of pollutant inside the vehicle through continuous inflow. Nevertheless the IO value for NO_2 remained high as in the previous case. Again the IO ratio was minimum during the minor traffic jam, except for the case of NO_2, due to its small variation.

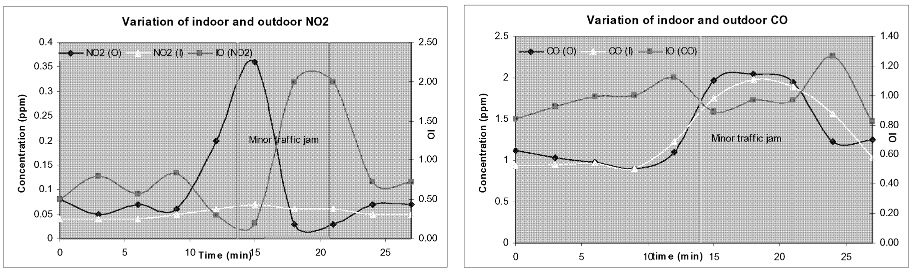


Figure 2: Variation of pollutant concentration characteristics on a highway using fresh air mode for NO_2, and CO

The same journey was travelled with all windows opened without air-conditioning and the pollution characteristics are shown in Figure 3. One thing deserves mentioning is the rapid and prompt response of indoor air. Indoor air inside the vehicle was generally less polluted but any rise in outdoor pollution was responded with a corresponding instant surge indoor. Because of full opening of window, indoor and outdoor air was experiencing very thorough exchange and it can be seen from the IO value that there was not too much difference in pollution level between indoor and outdoor air.

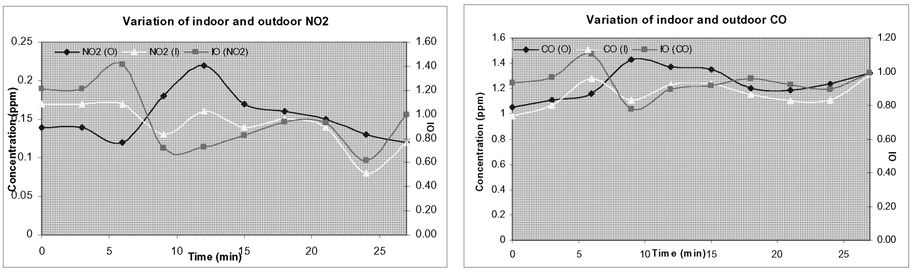
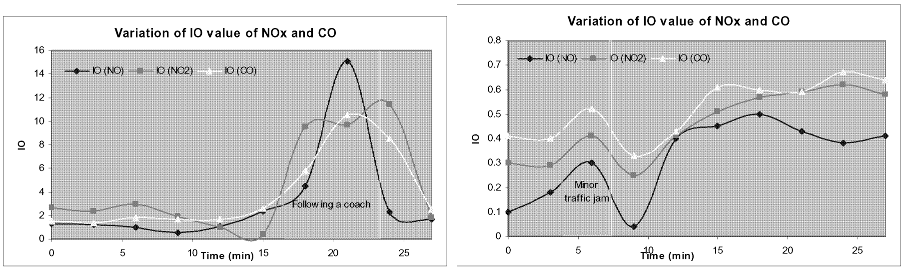


Figure 3: Variation of pollutant concentration characteristics on a highway with windows opened for NO_2 and CO.

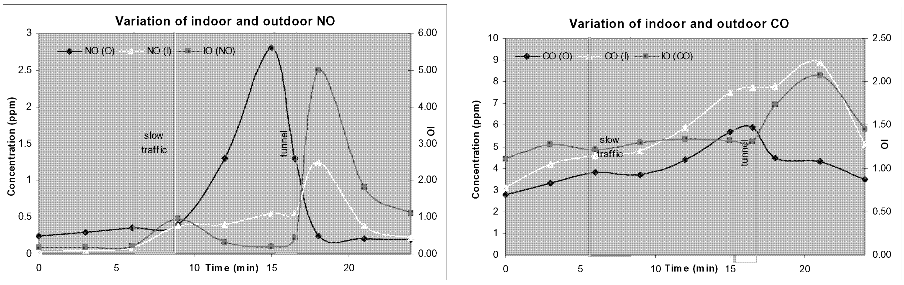


a) b)

Figure 4: Variation of IO ratio in countryside, a) with fresh-air mode, n) with windows opened

Figure 4 shows the variation of pollution level for the trip in a country park using air-conditioning. The trip was a fine ride with little and it can be seen that the IO value stayed above the value of one during the bulk of the journey. At the 21st minute, the IO value for NO reached a surprisingly high level of eight. The main reason was because the outdoor NOx concentration was very low due to the light traffic environment. In fact outdoor NOx varied around the value of 0.2 ppm only and the indoor NOx concentrations also showed little changes along the trip. On the other hand, the IO variation of CO was more gradual. During the journey, outdoor concentration for CO remained low, whereas there was a gradual increase of IO inside the vehicle, probably due to pollutant buildup. This could be seen at the end of the trip when the indoor CO concentration became almost twice that outdoors without apparent reason. The trip was repeated with all windows wide open as shown in Fig. 5b. It can be seen that the IO value remained lower than one throughout the journey due to thorough air exchange. It must be emphasized though, this occurs only when outdoor pollution level was low.

Results for a journey through an underground tunnel are displayed in Figs. 5. All IO ratios were found to be greater than one during the entire journey. In the latter part of the journey when outdoor air became cleaner, the IO values rose to unacceptable levels. The IO value only started to rise after exiting the tunnel as a result of in-vehicle pollutant accumulation. Indoor NO level reached a maximum after passing through the tunnel and reduced back to the original level shortly. Due to dilution, the pollution level indoor was conspicuously lower than that of air-recirculation.

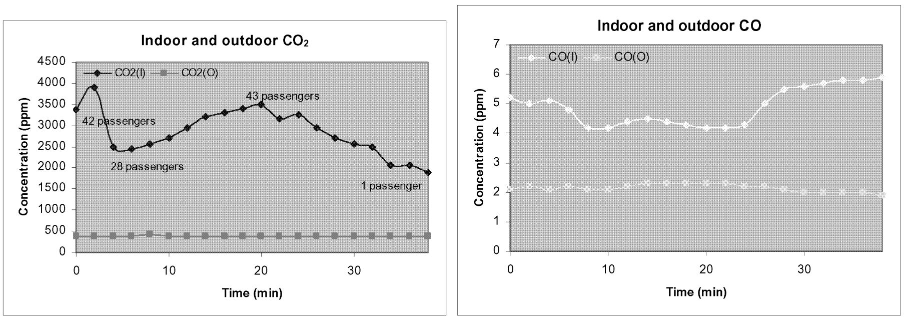


a) b)

Figure 5: Variation of IO ratio in a tunnel journey with with a) air conditioning and b) fresh air intake for NOx and CO.

3.1 Bus measurements

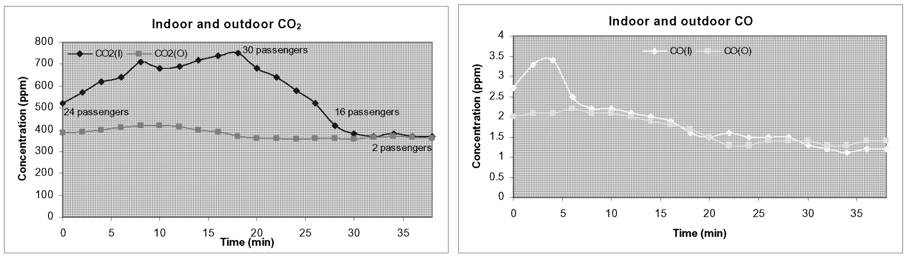
Figure 6 shows the variation of CO and CO_2 concentration level along a popular bus route from the Hong Kong Island to Kowloon. The route involves an air-conditioned bus travelling inside urban street canyons and a cross-harbour tunnel in between. An immediate observation is that there exists strong correlation between the number of passengers inside the bus with the in-vehicle CO_2 level. In fact the correlation coefficient between the two is extremely high (R = 0.9422), showing the strong connexion between the two. Out-vehicle ambient CO_2 level is relatively constant except for a very minor surge just outside the tunnel as explained in Chan (2003) and Chan & Chung (2003). It can thus be seen from the variation of IO ratio for CO_2 that the main source of this pollutant arises almost solely from the presence of human. When the bus was almost full, the CO_2 level reached an alarming level of more than 10 times that out-vehicle (3900 ppm), which is close to concentration of concern of the World Health Organization (American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), 2001). Obviously this has to do with two factors: limitation of air velocity to avoid discomfort and the lack of exhaust or dilution paths in a completely sealed bus compartment.



a) b)

Figure 6: Variation of pollutant concentration characteristics of an air-conditioned bus on an urban route for CO and CO_2.

The in-vehicle CO level is less alarming but is similarly concerning. Carbon monoxide is likely to come from outdoors, originating from emissions from other vehicles. In-vehicle CO level is constantly 2.5 times higher than that in an urban street canyon. The in-bus CO level fluctuates around 5 ppm which is one-fifth of the acceptable short-term exposure range (ASTER). However it is interesting to note that the correlation between the number of passengers and CO level is low (R = -0.6245), while the IO ratio shows very little variation due to the relatively small change in CO level throughout the journey.



a) b)

c)

Figure 7: Variation of pollutant concentration characteristics of a naturally ventilated bus on an countryside route, a) In-vehicle pollutant, b) Out-vehicle pollutant c) IO value

Another trip in the countryside was made with a non-air-conditioned bus. Figure 7 shows the variation of in-vehicle and out-vehicle CO and CO_2 level of the trip. The low CO and CO_2 level indicate thorough exchange of air between in-vehicle and out-vehicle during the journey. This is further supported by the fact that the IO ratio of the two pollutants remains only slightly higher than unity throughout. This is understandable as air movement inside the passenger compartment is less. It must again be noticed that the correlation between the in-vehicle pollution level and the number of passengers remain high (0.9353 for CO_2 and 0.6324 for CO). The trend and the magnitude of the IO variations are similar to that trip made in the urban setting.

4. References

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