Upward Extended Exhaust Pipe of Diesel-Powered Vehicles and its Effect on Pollutant Concentrations at Street Level

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Abstract : The exhaust pipe of an diesel-powered, six-wheeled air conditioned bus was extended from the original level at 0.52 m height to the bus roof level, around 4 m. Effects of the extension on the street level of air pollutants (CO, HC, PM10) at the sitting breathing level (1 m height) and 3 m from the traffic lane were assessed by both monitoring and modelling methods. Two street dispersion conditions in Bangkok were studied, the free flow highway and the street canyon, at various bus speeds (20, 40, 60 and 80 km/h). Maximum ambient air pollutant concentrations at the specified breathing level were compared between the original exhaust and the extended exhaust cases.

Monitoring results showed that upward extension of the exhaust pipe could reduce the maximum ambient pollutant concentrations from the passing bus emissions by a factor of around 1.25-3 times. Modelling was done only for the free flow highway using a Gaussian plume equation applied to the bus as a moving point source. The model results also showed that the extension of the exhaust pipe reduced the maximum ambient air pollution concentration by a factor of 3. The cost of the extension varies from US$ 35 to 50 for a simple external installation for a bus. A limited survey study showed a high acceptance rate of the technique by stakeholders though some subsidy may be required to promote its wide application.

Keywords : Diesel bus, Exhaust extension, Air pollution, Monitoring, Modelling, Social acceptance.

Introduction

Dense and congested traffic, combined with a fast growth in vehicle numbers are the main causes of serious air pollution problems in Bangkok [1]. Diesel-powered vehicles, such as trucks and buses, are of particular concern due to the potential toxic effects of their exhaust emissions. Diesel exhaust is a complex mixture of gases, vapours and fine particles containing harmful substances, which are recognized as human toxicants, carcinogens, reproductive hazards, or endocrine disrupters [2]. Presently, in North America and Europe most diesel trucks and buses have vertically extended exhaust pipes with average discharge levels set at 3-4 metres [3], thus exposure to the emission by people in the immediate proximity would be substantially reduced (Figure 1). In Thailand and other Asian developing countries, most of the diesel trucks and buses are designed to discharge exhaust at the street level (around 0.5 m above ground), which leads to higher exposure of riders of two wheelers, passengers in cars, people walking on the roadside and in crowded shop-houses bordering streets. The situation is worsened considerably when many buses and trucks are old with poor maintenance and are emitting a large amount of toxic substances. Extension of the exhaust pipe thus may be an appropriate short-term measure to reduce the exposure level, especially from older vehicles. This study has been designed to assess the effects of exhaust extension on ambient air pollution concentrations at the street level. Activities conducted in this study include: 1) On-road exhaust emission measurement and dispersion modelling, 2) Ambient air quality monitoring, and 3) Survey on social acceptance of the upward extended exhaust technique.

Methodology

The study used an unloaded 6-wheel bus with a diesel-fueled four-stroke compression ignition engine (CI). The volume of the engine was 13.741 litres. The exhaust pipe was originally located at the back of the bus at a height of 0.52 metres.

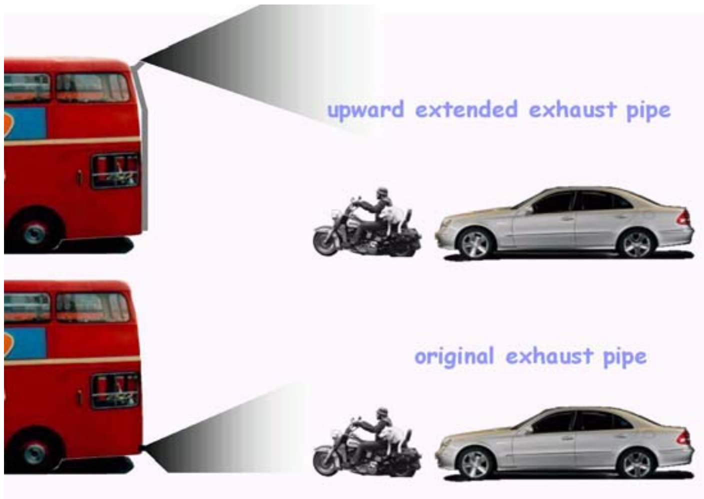


Figure 1. Exhaust gas from original and upward extended exhaust pipe.

Two streets in the Bangkok Metropolitan Region (BMR) were selected representing two typical dispersion conditions, i.e. the free flow highway and street canyon. Carbon monoxide (CO), hydrocarbon (HC) and respirable particulate matter (PM10) concentrations were measured at a fixed point on the downwind roadside of the bus lane (3 metres from the bus lane and at sitting breathing level or 1 metre height, Figure 2). The Chiang Rak Noi Road located at Klong Luang District, Pathumthani Province was selected to represent the free flow highway conditions. The width of the Chiang Rak Noi road is around 30 metres with a few low houses along the road. It is oriented in the east-west direction along the radial of 95 degrees (clockwise from North; North is 0 degree). Prachauthit Road in the Ratburana District of Bangkok was selected to represent the street canyon conditions. The width of Prachauthit Road is around 15 metres with many medium-high buildings (more than four-stories) bordering both sides of the road. It is oriented in the north-south direction along the radial of 15 degrees. During the daytime this road is highly congested, thus in order to assess the contribution from the study bus alone to the ambient pollutant concentration, the monitoring was undertaken at nighttime. For the Chiang Rak Noi Road the measurements were made during the daytime.

A steel pipe was used for the exhaust extension to above the bus roof height and was held with wire at the right of the rear of the bus for temporary use in this study. The end of the 5-inch diameter original exhaust pipe (horizontal) was modified and connected to a 3-inch diameter steel vertical pipe. The end of the vertical extension was set to emit the exhaust at a 45-degree angle above the horizon (as shown in Figure 4). The end of the upward extended exhaust pipe was located at 3.95-metres above the ground level.

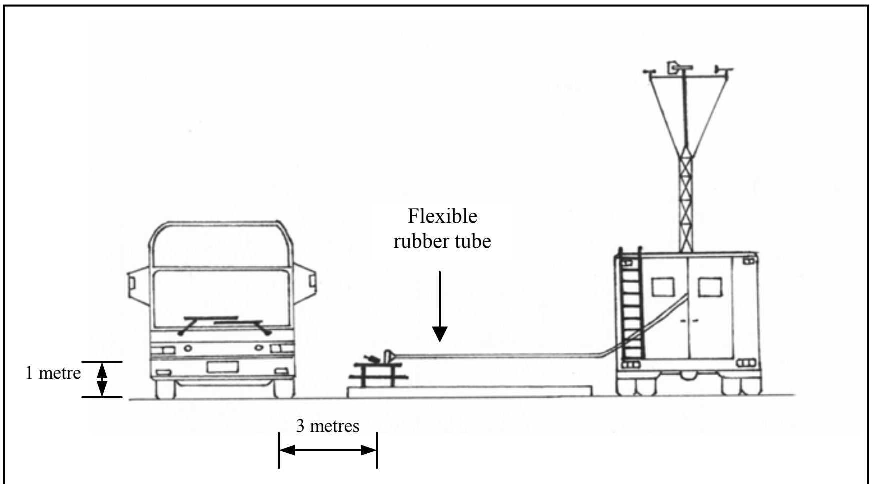


Figure 2. Ambient air monitoring equipment and location of the sampling site.

1. On-road emission measurement and dispersion modelling of exhaust gas

1.1 On-road emission measurement

A five-gas analyzer system was installed in the bus to measure hydrocarbons (HC) and carbon monoxide (CO). The exhaust gas sample was taken before it mixed with the ambient air. Simultaneously, measurement of the opacity was done using an opacimeter at the end of the exhaust pipe. A special sampling tube, "Tee" shape, with 3 inch diameter was fabricated and installed at the end of the original exhaust pipe, as seen in Figure 3. Inside the tube, glass wool was used to pre-filter particulate matter before a sampling stream of exhaust gas was drawn through a teflon tube (sampling line) to the five-gas analyzer placed inside the bus. The opacimeter sensor was installed at the end of the "Tee" tube while the measuring equipment was inside the bus. The sampling lines (the five-gas analyzer and the opacimeter) as well as the draining exhaust gas emission tube (after passing the five-gas analyzer) were routed through a drainage hole at the right side of the bus. On-line recording of pollutants was made every 10 seconds while the bus ran at stable speeds of 20, 40, 60 and 80 km/h. For each bus speed, engine speeds were recorded and the exhaust gas temperature was measured by a digital thermometer with the sensor placed inside the exhaust pipe (Figure 3). The on-road exhaust emission measurement data were processed and used for the dispersion model input.

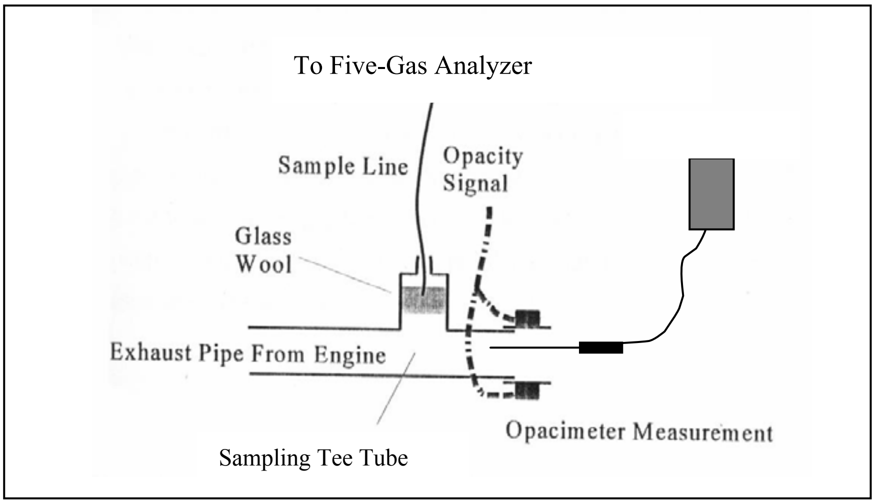


Figure 3. Schematic detail of exhaust gas sampling system.

1.2 Exhaust Gas Dispersion Modelling

The Gaussian plume equation with 100% reflection from the ground (Equation 1) was used for the running bus as a moving point source. Ambient concentrations at various distances behind the bus were estimated using this model.

Equation 1

$$C\,(x,y,z;H)=\frac{Q}{2\pi\,u\,\sigma_y\sigma_z}\left[\exp\frac{-y^2}{2\,\sigma_y^2}\right]\left[\exp\frac{-(z-H)^2}{2\,\sigma_z^2}+\exp\frac{-(z+H)^2}{2\,\sigma_z^2}\right]$$

where,

C	=	Ambient air pollutant concentration, g/m^3
Q	=	Source strength or emission rate, g/s
u	=	Average plume transport velocity, m/s
H	=	Effective discharge height, m
σ_y	=	Cross wind dispersion coefficient, m
σ_z	=	Vertical dispersion coefficient, m

Emission rate from bus exhaust

Pollutant emission rate was obtained as the product of emission concentration (obtained directly from on-road emission measurement) and the exhaust gas flow rate. The latter was calculated following the method proposed by [4] as shown in Equation 2.

$$V_{air} = \frac{V_{eng} \times (RPM) \times EffVol}{Cycle} \qquad \text{Equation 2}$$

where,

V_{air}	=	Volumetric flow rate of air through engine, L/min
V_{eng}	=	Swept volume of the engine, L
RPM	=	Engine speed, rounds/min
Cycle	=	Number of times the engine turns over to displace its total swept volume (2 for four-stroke engine)
EffVol	=	Approximate volumetric efficiency. EffVol was obtained from the graph of relationship between volumetric efficiency and speed range [5]

Plume rise

When a hot plume is released from a stack tip with a certain exit velocity it would rise to a certain height while dispersing downwind before spreading horizontally. The effective height in Equation 1 is calculated as the sum of the plume rise and the physical height of the stack tip.

In this study, the exit velocity of the flue gas was high (16 to 38 m/s) and the gas was hot, hence the plume rise should be important. However, for the original exhaust case, the exit direction was horizontal and the plume rise was neglected. For the case of extended exhaust, the plume rise was calculated using the Briggs' method presented in [6] for unstable dispersion conditions (unstable dispersion conditions were assumed for both plume rise and plume dispersion modelling due to the increased turbulence on the road by the vehicle motion and high exhaust temperature). A gradual plume rise scheme was used and the rise was calculated for every second until the final rise was reached. The high exit velocity of the plume has resulted in only the momentum dominated cases. The high exit velocity also justifies the assumption of no plume downwash. Due to the inclined exhaust pipe (45°) the vertical component of the plume exit velocity ($R_{vertical} = V_g \sin 45°$) was used as the Vs in the Briggs' formula.

Plume transport velocity

When the bus is moving there are three vectors to be considered for plume transport, namely, vector of airflow passing over the bus (V_B), exhaust gas velocity vector (V_g), and average wind vector (U). The X axis was directed along the horizontal transport vector, R_T.

For the case of upward extended exhaust pipe, in the first stage when the plume was rising gradually before reaching the final rise, its horizontal transport velocity is depicted in Figure 4 and calculated using Equation 3. After the plume reaches its final/maximum rise, it spreads horizontally with the transport velocity determined by Equation 4. For the case of the original exhaust pipe, no plume rise was considered, hence the plume transport velocity was also only determined by Equation 4 as seen in Figure 5. The transport speed was first calculated and substituted for *u* value into Equation 1.

Resulting vector of plume horizontal transport during rising:

$$R_T = V_B + V_g \cos 45° + U \qquad \text{Equation 3}$$

Resulting vector affecting plume horizontal transport in plume spreading:

$$R_T = V_B + U \qquad \text{Equation 4}$$

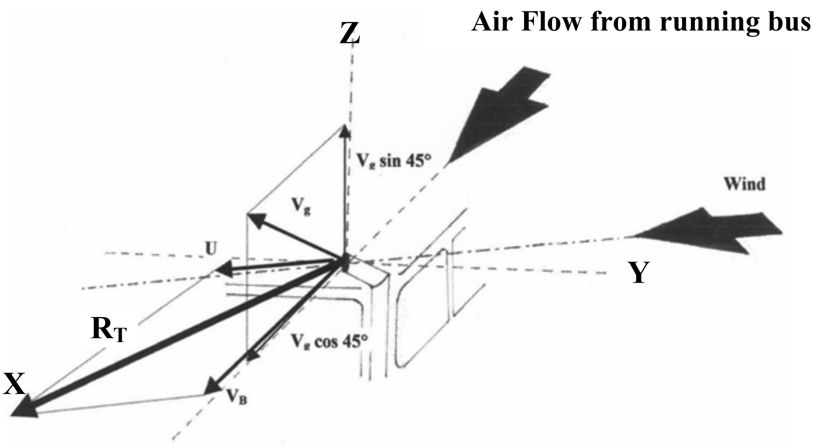


Figure 4. Plume transport vectors during rising phase (Equation 4).

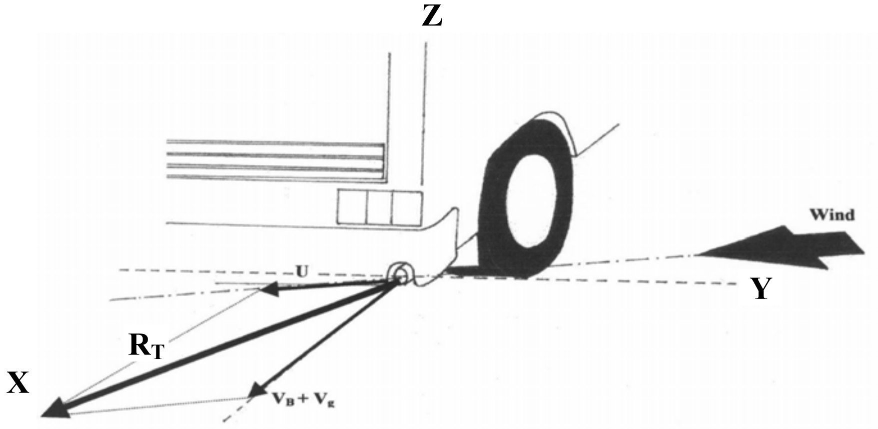


Figure 5. Plume transport vector during horizontal spreading phase (Equation 4).

The vehicle-induced turbulence behind the bus was accounted for by using the σ_y and σ_z presented in HIWAY2 model [7] which are higher than the Pasquill dispersion coefficents. The blocking effect of the bus on wind immediately behind the bus was neglected. This effect could be pronounced for the case of original exhaust pipe when there is a head wind and the bus is in motion. In this case, plume transport a short distance behind the bus would mainly follow the plume exit velocity from the exhaust. In addition, the airflow passing the bus was assumed to be equal to the bus speed, i.e. no atmospheric and bus friction were accounted for. Only the short term modelling is used (30 minutes for sigma, [8], the reactivity of pollutants was neglected and both HC and CO were considered conservative.

2. Ambient air quality measurement

Ambient CO and HC were measured by the respective automatic analyzers, which are built-in to a mobile ambient air quality monitoring station with the sampling point shown earlier in Figure 2. Simultaneous measurement of PM10 was done at the same sampling point using a portable dust monitor (GRIMM dust monitor series-1100 v.5.10E). The data were recorded every second, well before the bus passed the sampling site to record the background concentration and continued until the pollutant levels reduced to the background concentration again after the bus passed. On average the recording periods were about 2 minutes for each test. At the free flow highway road, (the Chiang Rak Noi), the bus speeds were maintained at 20, 40, 60 and 80 km/h while at the Prachauthit Road the speeds were 20, 40 and 60 km/h. This was to reflect the actual speed limitations at busy streets inside the city. Measurements were conducted when the roads were not crowded to ensure as much as possible that the contribution to the concentration peaks were from the study bus only. Any tests which clearly did not meet this condition were discarded. For the same reason the measurements taken at the busy city street, Prachauthit Road, were made during nighttime. Simultaneously, the wind speed and wind direction were also measured using the built-in meteorological equipment in the mobile station.

Results and Discussion

1. On-road exhaust emission measurement

The HC and CO concentrations in the exhaust did not change much when the bus was maintained at a desired speed. However, the opacity (a measure of particulate emission) fluctuated largely. Less black smoke was emitted when the bus was running at a stable speed. It was, however, quite a challenging task for the driver to maintain the bus stable at the desired speed for all the emission measurement periods of 5 minutes. There were many factors reducing the bus speed such as a bridge, roughness of the road and other traffic. Therefore, accelerations and decelerations were necessary to bring the speed back to the desired level, which were associated with high black smoke emission. The average on-road measurement results are presented in Table 1. The data were used to determine the emission rate using Equation 2 and the results are presented in Table 1.

Table 1. Relationships between bus speed, engine speed, average emissions and emission rate.

Bus speed (km/h)	Engine speed (rpm)	Hydrocarbon (ppm)	Carbon monoxide (ppm)	Opacity (%)	Exhaust gas temperature (°C)	Emission rate (m^3/s)
20	800	16	312	0.13	86	0.073
40	1000	17	225	0.10	88	0.093
60	1500	20	145	0.31	90	0.144
80	1800	25	153	0.22	98	0.174

2. Assessment of effects of extension

2.1 Results of dispersion modelling

The considered distances along the horizontal transport vector (R_T) during the plume spreading phase include X = 0, 0.5, 1, 2, 4, 8, 10, 15, 20, 25, 30, 40, 50, 60, 80, and 100 metres from the running bus for the free flow highway conditions. The concentrations at the plume centerline (y = 0) and at receptor height z = 1 metre were calculated. This simple model (Equation 1) does not consider the street canyon effects, therefore it was applied only for the free flow highway condition, i.e. the Chiang Rak Noi Road. The calculation was made for all 4 considered bus speeds for HC, CO and opacity, which is closely related to PM10 [6]. Due to the short term dispersion from the exhaust source, the assumption on conservative pollutants was used for all 3 pollutants, hence the dispersion of these pollutants would change in a similar way when the exhaust is extended from the original exhaust pipe level. Therefore, only HC was modelled. The model results for HC for various hypothetical ambient wind directions are illustrated in Figure 6 for the Chiang Rak Noi Road. The 30-year average wind speed in Bangkok (30-year average data in April from the Don Muang airport station of the Meteorological Department) of 3.2 m/s was used in the model.

For all wind directions, the extension of the exhaust pipe has resulted in a reduction of the simulated plume centreline pollutant concentration by a factor of around 3 times (Figure 6). Considering the variation of the pollution with wind direction, it is shown that the highest concentration was obtained for the 275°- wind direction (from the west). As metioned earlier, the Chiang Rak Noi Road is oriented almost East-West at the radial of 95° from the North. In the calculation, it was assumed that the running direction of the bus was from the West to the East. Thus, the highest pollutant concentration was obtained when the wind blows in the same direction of the bus or opposite to V_B, which resulted in the lowest plume transport velocity (*u* value in Equation 1). In this particular case, all 3 vectors (wind, V_B and R_T) are on the same line and the centreline of the plume was parallel to the road leading to higher exposure to people on the road, e.g. motorcycle riders. The minimum pollutant concentration was obtained when the wind blows against the bus movement or in the same direction as V_B, around 95°, which resulted in the largest plume transport speed. The variation of pollutant concentrations with the distance along R_T for the two cases is presented in Figures 7a and 7b, respectively. The larger difference in pollutant concentrations was thus observed at short distances from the running bus and no practical difference was observed for the distance larger than 80 m.

In principle, the Gaussian modelling with reflection from the ground produces a maximum concentration of pollutants at the ground level (z = 0 m) in the down transport direction. In this study the maximum concentration at the sitting breathing level (z = 1 m) and the distance where it ocurrs were also simulated. The results showed that the maximum HC concentration at the sitting level, for the original exhaust pipe, occurred almost at the end of the exhaust pipe, i.e. x = 0. For the upward extended exhaust pipe to 3.95 m in this study, the maximum concentration occurred at x around 8 m (Figure 7). The maximum down transport concentration of original exhaust pipe (0.52 m above ground) is greater than the maximum concentration of upward extended exhaust pipe (3.95 m) by a factor of 2.96-2.99 or around 3.

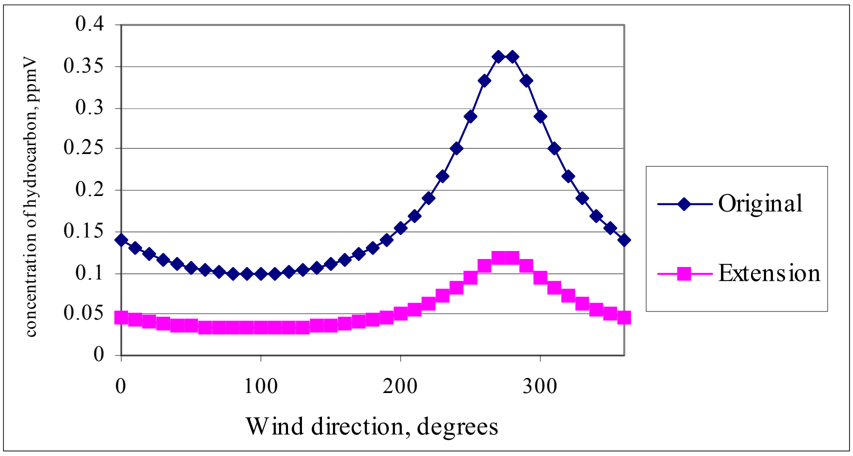


Figure 6. Plume centreline HC concentration for different wind directions at the bus speed of 20 km/h and wind speed of 3.2 m/s.

Thus, in the original exhaust pipe case, due to the lower plume centreline, the exhaust plume reaches the ground very quickly producing the maximum concentration close to the exhaust release point. Figure 8 also shows the effect of extension height on maximum down transport concentration at 1 m above ground.

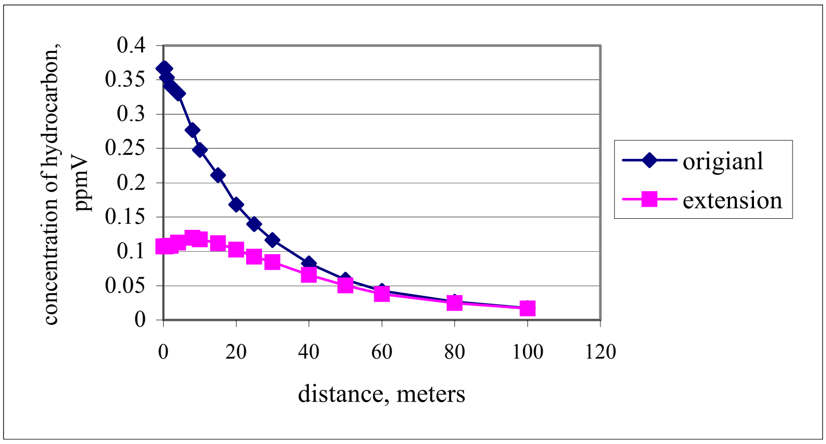


Figure 7a. Simulated plume centreline HC concentrations for the original and upward extended exhaust pipe at various distances along R_T, wind direction 275^o. (Bus speed of 20 km/h)

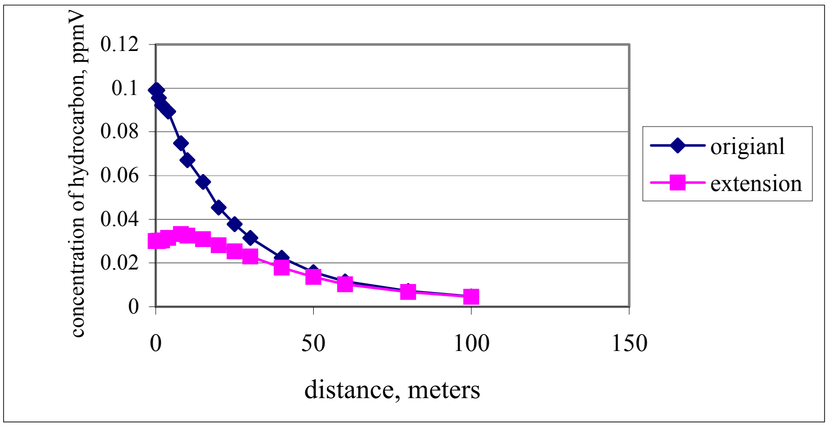
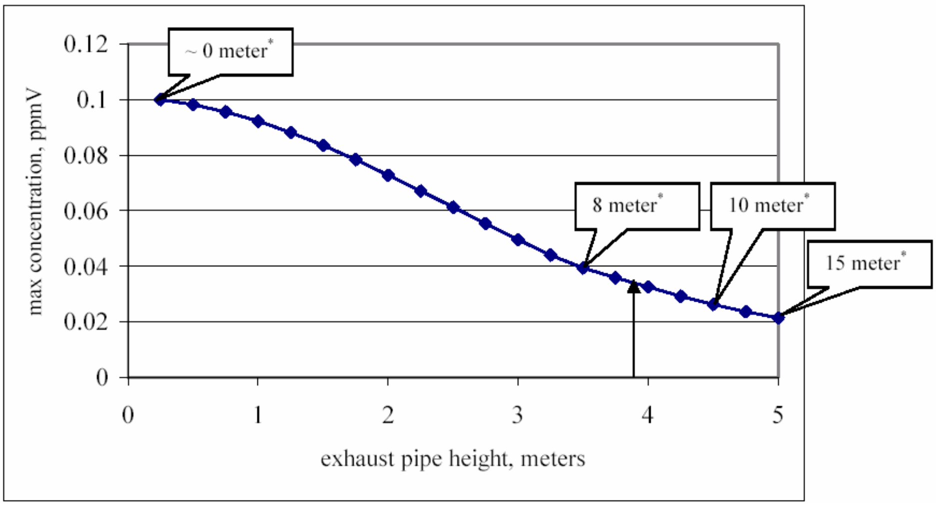


Figure 7b. Simulated plume centreline HC concentrations for the original and upward extended exhaust pipe at various distances along R_T, wind direction 95^o. (Bus speed of 20 km/h)

For other bus speeds, the effect of extension height on maximum downward transport concentration at 1 m above ground and the distance where it occurs are similar but the maximum concentration value is different due to the different pollution emission rate.



* Distance from the bus where the maximum concentration occurs.
The height of the extended exhaust pipe in this study (3.95 m) is marked by the arrow.

Figure 8. Maximum downwind concentration and distance where it occurs for different exhaust pipe heights (wind direction of 95^{o} and bus speed of 20 km/h).

2.2 Results of ambient air quality measurement

Ambient concentration depends on many variables including emission, meteorology, and terrain. Wind speed and wind direction, in particular, can affect the pollutant dispersion and resulting ambient concentrations from the bus exhaust. In this study the experiments were conducted in the open air, i.e., in uncontrolled conditions. There was only one bus used in this study, hence simultaneous monitoring for both the original and the extended pipe was not possible. As a result, monitoring for the original and extended exhaust cases was conducted within a 3-4 hour period for each street. The recorded wind data during the period showed substantial variations in speed and direction. In fact even small changes in wind direction may have a significant impact. For the 25 cm diameter of the conical sampling intake opening used in this study, which was mounted at the monitoring site, 3 m from the bus, a change in wind direction of 2.6° would be enough for the intake to fail to catch the exhaust plume centerline concentration. Wind direction change by more than 2.6° would lead to incomparability of the results between the 2 sets of the experiments (original and extended exhaust pipe cases). Therefore, to assess the impact of the exhaust extension it was essential to select data from the experiments conducted when wind speed and wind directions between the two tests are similar. A few tests satisfied this condition and showed that the extension would reduce concentrations at breathing level. The magnitude of reductions differs from test to test and they were in the range of 1-3. For HC shown in Figure 9a the reduction in maximum concentration is around 3 times but for PM10 shown in Figure 9b it is around 1.5 times. Settling of particles may partly contribute to this discrepancy.

Our study also found that there is not much reported data available from the literature. Weaver et al. [3] estimated that an exhaust pipe extension above the vehicle roof would reduce concentration of pollutants behind the vehicle by 65-87% or from 3 to 7.6 times. Another study, as cited by [3], found that the extension reduced pollutant concentration at the breathing zone near a bus station by 8 times.

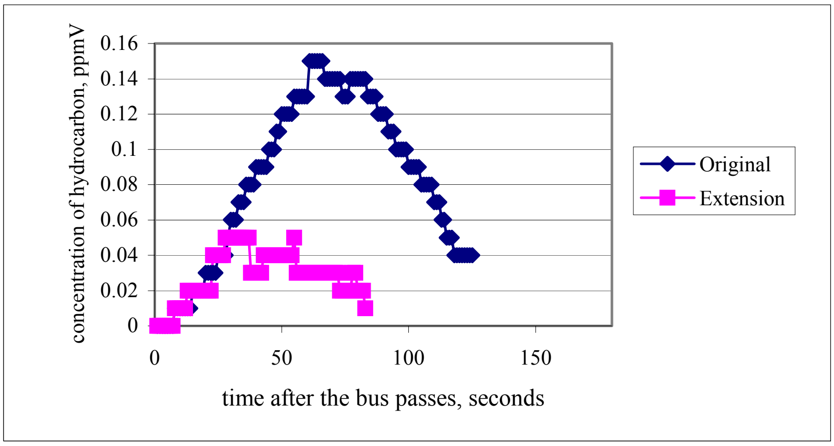


Figure 9a. Ambient HC concentration at Chiang Rak Noi Road when the bus is passing at 40 km/h (background concentration was excluded).

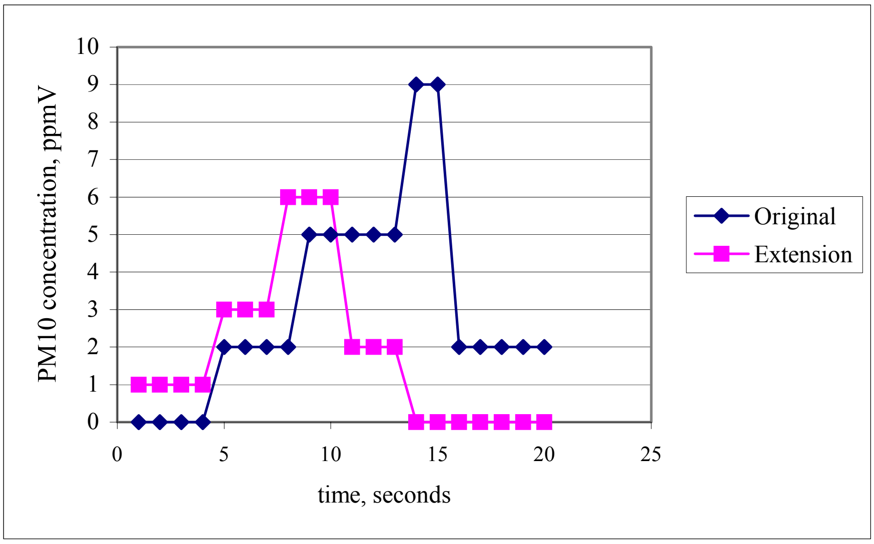


Figure 9b. Ambient PM10 concentration at Chiang Rak Noi Road when the bus is passing at 20 km/h (background concentration was excluded).

2.3 Comparison between monitoring and modelling results

Since the measurements were done for 4 bus speeds for each case, i.e., the original and extended pipe cases, three tests were conducted for each speed resulting in 24 data points. The difference between the recorded peak value and the background (Figures 9a and 9b) was considered to represent the contribution of the passing bus emissions to the ambient concentration at the monitoring location. The difference was used for comparison with the modelled results. The latter were the maximum ambient concentrations resulting from the bus emissions which were calculated for the same mean wind direction and speed recorded during the tests.

To enable comparison, first both monitoring and modelling results were converted to the same average time basis. The dispersion coefficients used in this study were the average of 30-minute sampling [8], as mentioned earlier. The ambient air measurements were done for a 3 second sampling period. Conversion of the modelling results at 30-minute sampling to the 3 second sampling concentration was made using Equation 5 [6, 9].

$$C_2 = C_1 \left(\frac{t_1}{t_2} \right)^q \qquad \text{Equation 5}$$

where,

C_2 = Concentration at sampling period t_2 (minute)

C_1 = Concentration at sampling period t_1 (minute)

q = Constant

The q value found in the literature varies widely. There is strong solar radiation and the wind speed is 3-4 m/s during the experiment. Therefore, unstable condition, Class B, was taken. In this study a constant value (q) equal to 0.535 was used. This is the average between the value suggested by the US-EPA (0.52) and the value suggested by the State of Texas (0.55) for stable Class B as presented in [8]. The t_1 value was 30 minutes and t_2 was 3 seconds.

Simulated and measured 3-second average CO and HC concentrations for Chiang Rak Noi Road were plotted in Figures 10 and 11, respectively. The agreement seemed to be better for CO in the extended exhaust and for HC in the original exhaust. The model overestimated CO for the original exhaust and underestimated HC for extended exhaust in some cases. There might be many factors contributing to the discepancies. Uncertainty in the model results may be related to 1) use of a simple Gaussian equation, 2) assumptions made in model formulation, 3) errors in etimation of dispersion coefficients and emisison rates, and 4) others. The monitoring could not be error free either. High fluctuations of wind during the measurements may produce errors as mentioned ealier. The short averaging time (3 seconds) used in monitoring, which was necessary to generate enough data points, would produce monitoring results that vary substantially due to wind fluctuations and atmospheric turbulence.

Nevertheless, in general the modelling and monitoring results are considered to be in reasonable agreement, especially when the concentration range is considered for HC, for example. The ratio between modelled and measured values for HC varied from 0.2 to 2.4 with an average of 0.9. For CO, the ratio varied from 0.5 to 14.5 with an average of 3.3. The upper values of the ratio for CO were caused by 2 cases for the orginal exhaust when modelled CO values were much higher than the monitoring results. This would be interesting to further investigate but it is beyond the scope of this study.

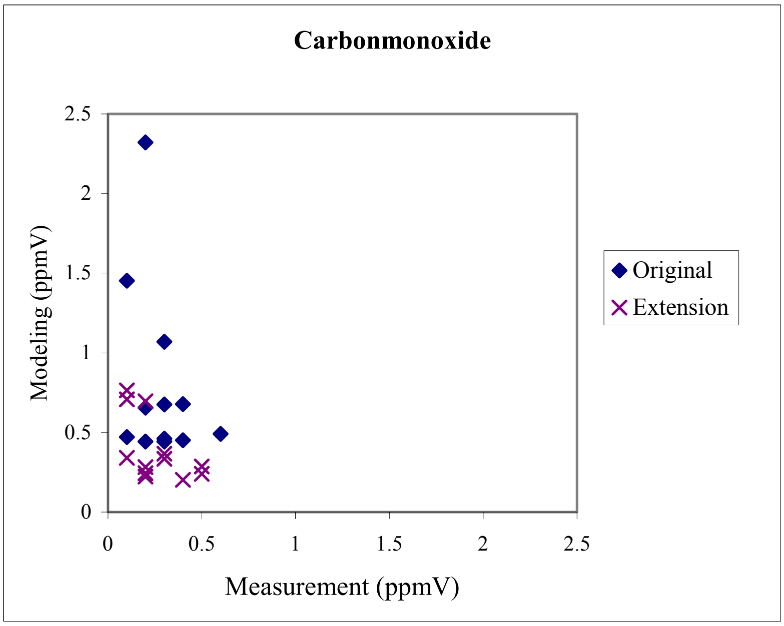


Figure 10. CO concentration by measurement and modelling.

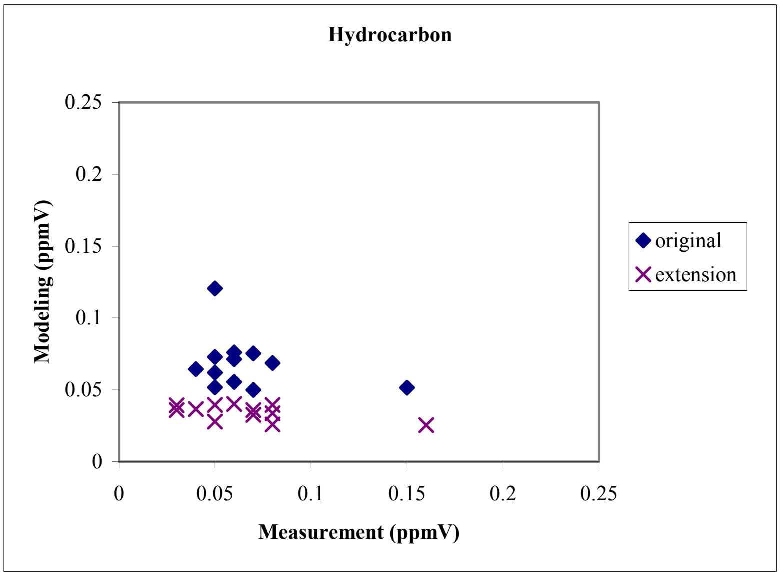


Figure 11. HC concentration by measurement and modelling.

3. Socio-economic aspects of the upward extended exhaust pipe technique

3.1 Cost of the upward extension

Cost of the bus exhaust pipe extension was estimated for different pipe materials and installation options (outside or inside the bus body). The simple temporary upward extension used in this study had a material cost of around US$35 and a more permanent extension is estimated to cost around US$50. It takes 2-4 man-hours to make a simple installation.

However, re-routing the exhaust pipe within the bus body/shell would provide a much better appearance. In this case, heat insulation material should be used for the vertical exhaust pipe inside the bus and the interior design should be properly done. This would cost around US$230 to 450 depending on the materials used and take 1-2 man-days for the installation.

Similar consideration could be made for diesel trucks. However, retrofitting vertical exhaust extensions to trucks with horizontal exhausts would be feasible in some cases and not in others. This is due to limits imposed by truck design and use, such as garbage trucks or specialized construction vehicles. In Thailand, for example, most heavy-duty trucks are designed to emit their exhaust at the back. However, upward extended exhaust pipe at the back of trucks is not convenient because the vehicles are usually designed with a fold down tray for unloading/loading materials or goods. In such cases, the exhaust pipe could be rerouted to the gap between the cabin and the truck body. The cost for this would be US$50 to 70 for a steel pipe and US$230 to 350 for stainless steel. Around 1-2 man-days would be required for installation.

3.2. Social acceptance of the upward extended exhaust pipe technique

The social acceptance of the technique was studied by interviews and questionnaires to stakeholders including 1) bus manufacturers, 2) bus drivers 3) bus owners, and 4) the general public. A total of 53 responses were obtained which included 3 manufacturers, 25 drivers, 10 bus owners and 15 members of the general public.

Results of the interviews and questionnaires presented in Table 2 show that, in general, the technique was acceptable for most of the groups except for the bus owners who did not feel secure about the bus appearance. Some drivers shared the same concern. None of the groups would be willing to pay for the cost, except for the manufacturers who would eventually transfer the cost to the buyers. To successfully promote the technique an initial subsidy might need to be considered to reduce the costs. The potential reduction in maximum ambient concentrations and the associated health benefits should be widely disseminated in order that such benefits outweighing the small investment cost may help to promote the technique widely.

It is speculated that some power loss may be associated with the upward exhaust extension. However, in urban areas buses do not normally run at the maximum power output hence the power loss and subsequent fuel economy effect would not be substantial.

It is necessary to note that this technology can only lead to reduction of exposure in the immediate vicinity by reducing the high concentration at the breathing level. It cannot reduce the total emissions from buses and trucks to the atmosphere. The reduction of exposure to high local concentrations would lead to a reduction of both chronic and acute health effects from diesel exhaust. Considering the actual situation of many developing cities, where an old and highly polluting fleet of diesel buses and trucks are still in the streets, implementation of this low cost technique could be a workable shortterm measure to reduce adverse health effects from vehicle emissions. The longer term solution to the problem might be lesser vehicles of this type in the cities and using cleaner technology. This in turn requires both technological measures such as exhaust cleaning or fuel alternatives, as well as improved traffic management which can in turn lead to a reduction of emissions into the environment.

Table 2. Social acceptance.

Parameters	Drivers (25 resp.)	Bus Owners (10 resp.)	Public (15 resp.)	Manufacturers (3 resp.)
Accept	80%	0%	100%	100%
Not accept	20%	100%	0%	0%
Willing to pay	0%	0%	0%	100%*

* = The cost would be transferred to buyers

Conclusions

The upward extension of the exhaust pipe to emit pollutants above the bus roof leads to a reduction of exposure in the immediate vicinity to the maximum ambient pollutant levels by a factor of around 3, as compared to the original horizontal exhaust pipe. Though the technique will not affect overall pollutant emissions to the atmosphere it would be suitable as a short-term retrofitting measure for older or poorly maintained vehicles.

The material and installation cost is reasonable. A better design for the extension to make it more attractive, possible subsidies and awareness raising would promote the technology for wider application. The technique could be used in combination with other long-term techniques to eventually improve urban air quality.

Further study on the effect of the extension to engine power and fuel economy should be made to gain better understanding of the socio-economic impact of the extension and to promote the technique.

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