Characterization of particulate matter in the tropics

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ABSTRACT
This paper reviews the exposure to particulate matter on bus stops during peak traffic hours. The methodology involves monitoring of total suspended matter, PM_{10}, $PM_{2.5}$ and PM_1 using Grimm Dust Monitor for a period of five weekdays. Traffic flow and relevant meteorological parameters were also recorded. The exposure to particulate matter is critical since fine particles get deposited into the respiratory tract and can lead to various respiratory diseases and premature deaths. The study shows that PM_{10} comprises almost 80% of the total suspended particulate matter. PM_1 could comprise up to 83% of PM $_{2.5}$, which could be critical as surface number dose will be much higher for finer particles than for coarse particles. In addition, it was observed that PM_1 gravimetrically comprises $62.2 \pm 4.9\%$ of PM_{10} whereas on basis of number density, PM_1 comprises $99.5 \pm 0.3\%$ of PM_{10}. The concentration of PM_1 is significant as it could have adverse health impacts on the lung with greater penetration. The infiltration of particulate matter into the building will depend on size of particulate matter, filtration characteristics, properties of building envelope, etc. Hence, there is a need to have further research in this area.

INDEX TERMS
Particulate matter; Indoor–Outdoor ratio; Effect on health; Tropics; Filtration

INTRODUCTION
Urban population is frequently exposed to high air pollution concentration, where motor vehicle emissions constitute main source of fine and ultra fine particles. Hoek *et al.* (1998) discovered that a 10 $\mu g/m^3$ increase in PM_{10} is associated with a 10% decrement in children's peak expiratory flow. The estimated increase in the relative rate of death from cardiovascular and respiratory causes was 0.68% for each increase in the PM_{10} level of 10 $\mu g/m^3$ (Samet *et al.*, 2000). Many studies consistently show the direct link between mortality rates and daily ambient concentrations of suspended matter that have diameter below 10 μm. According to the health statistics issued by the Ministry of Health, Singapore (Ministry of Health Singapore website), 24 % of the total deaths in 2002 (preliminary statistics) were due to cardiovascular diseases and 0.7% of the total deaths were due to bronchitis, emphysema and asthma.

Motor vehicles and combustion-related processes mostly generate fine and ultra-fine particles. A study on characterization of airborne particle in Beijing showed that 99% of airborne particles are in PM_{10} and $PM_{2.5}$ and about 94% dust storm particles are in the respirable fraction and roadside PM_{10} showed that particles less than 1 μm accounted for 98% of total particulate matter (Zongbo *et al.*, 2003). It has been postulated that ultra-fine particles have the ability to penetrate lung walls inducing inflammation in the pulmonary interstitum, which in turn stimulates the production of clotting factors in the blood

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responsible for the recognized ability of airborne particles to exacerbate ischaemic heart disease (Seaton *et al.*, 1995). One of the more interesting findings from the toxological studies suggests that ultra-fine particles of less than 100 nm have considerably enhanced toxicity per unit mass and that their toxicity increases as particle size decreases (Donaldson and Macnee, 1998). It may be attributed to the fact that fine/ultra-fine particles have higher surface area per unit mass. It was estimated that 6% of the deaths in Europe (1 in 17) could be blamed on particulate matter caused by traffic fumes (Colvile *et al*., 2003).

The outdoor air quality has a significant effect on indoor air pollution levels, and occupants spend most of the time indoors. Knowledge about the influence of ambient air pollution on the concentration in indoor environment is, therefore, crucial for assessment of human health effects from traffic pollution. Concurrent indoor and outdoor 10 min averaged $PM_{2.5}$ and PM_{10} concentrations to establish the indoor–outdoor PM correlation for typical west Texas residences equipped with evaporative coolers showed that if the ambient PM concentration remains steady, a 10-min average indoor air sample after the first 10 min period would contain 99% outdoor air and a 1 h average indoor air sample would actually be represented by 95% of the outdoor air. In addition, a strong diurnal pattern of PM_{10} indoor and outdoor was observed in nine out of the 10 tested houses independent of the possible human activities and other indoor sources at each residence (Wen-Whai *et al*., 2003). Studies conducted by researchers (Morawska *et al*., 2001; Chao and Wong, 2002) show that outdoor PM concentration could be used to predict indoor concentration.

In a well-sealed mechanically ventilated building, the majority of outside air enters through prescribed inlet and Green and Etheridge (1998) showed that the indoor air quality can be significantly improved by drawing air from less contaminated sides of the building. In the case of naturally ventilated buildings, infiltration is a function of wind and buoyancy pressures acting across the envelope and characteristics of flow path between the inside and outside of the building (CIBSE, 1997).

The objective of this experiment was to assess the exposure of commuters to particulate matter at bus stops. Traffic flow and meteorological conditions were recorded. To date, very few field measurement data sets have been presented for the evaluation of roadside emission and dispersion of particulate matter with simultaneous monitoring of total suspended matter, PM_{10}, $PM_{2.5}$ and PM_1 in the tropics. Such information is very crucial in evaluating the exposure of population to PM in urban and road side environment and is beneficial in accessing the migration to the indoor environment. Design of building requires meaningful I/O ratios to ascertain the level of pollution that infiltrates into a naturally ventilated building. Particles are often quantified in terms of mass. Many studies suggest that the correlation between particle concentration and health effect increase with decreasing diameter. Hence, it becomes important to determine the number of particles in order to further assess and quantify the risk levels.

METHODOLOGY

The experiments were carried out at a bus stop along Ayer Rajah Expressway, Singapore, which is the most important road network in Singapore having a very high traffic density. Figure 1 shows the site map with the bus station number 8. The situation is of special concern during the peak traffic hours, as there are a large number of people commuting by buses. In such a situation, the short-term exposure becomes quite significant. One set of Grimm 1.108 was used to measure the gravimetric mass while the other set (Grimm 1.108) was used to measure the particle count during the peak traffic hours. Meteorological information like temperature, relative humidity and wind speed were also recorded during the period of measurement using HOBO and Anemomaster. Traffic Data was obtained from the Land Transport Authority, Singapore.

Figure 1 Site map (Source: Street directory website).

RESULTS AND DISCUSSIONS

Meteorological and Traffic Conditions during the Period of Observations

During the period of observation, the ambient air temperature was 31.5 ± 3.5°C with relative humidity of 71.2 ± 13.4 %.The wind on site was calm with 0.48 ± 0.2 m/s. The hourly traffic flow during the peak traffic hour on the expressway varied as 70063 ± 12,500 vehicles/hour.

Table 1 Constituents of PM ($\mu g/m^3$)

S.No.	Day	Time	TSP-PM_{10}*	$PM_{(10-2.5)}$*	$PM_{(2.5-1)}$*	PM_1*	Temp(°C)	RH %	Wind Sped(m/s)	Traffic Count
1	Monday	4:30PM-5:30 PM	13.11	9.99	5.38	31.51	31.92	69.97	0.73	78840
2		5:30 PM-6:30 PM	12.25	9.60	5.43	30.79	31.50	71.55	0.78	81540
3		6:30 PM-7:30 PM	16.91	16.12	6.61	34.39	29.86	79.63	0.35	70860
4	Tuesday	4:30PM-5:30 PM	2.66	4.77	3.24	18.64	26.82	91.99	0.65	79020
5		5:30 PM-6:30 PM	2.46	3.97	2.73	15.02	27.49	86.83	0.58	87660
6		6:30 PM-7:30 PM	4.39	4.74	3.31	12.23	26.85	89.42	0.20	70560
7	Wednesday	4:30PM-5:30 PM	11.58	12.05	5.63	25.60	36.63	55.22	0.57	78600
8		5:30 PM-6:30 PM	25.12	13.12	5.29	25.44	32.83	62.86	0.54	53400
9		6:30 PM-7:30 PM	17.11	15.53	5.67	26.11	30.50	70.79	0.20	66420
10	Thursday	5:30 PM-6:30 PM	3.03	6.90	4.54	21.28	31.75	69.88	0.31	55800
11		6:30 PM-7:30 PM	2.87	6.98	4.51	20.99	30.14	77.04	0.27	70380
12	Friday	4:30PM-5:30 PM	12.51	10.09	5.36	24.10	39.28	44.36	0.52	76020
13		5:30 PM-6:30 PM	12.25	11.22	5.32	23.47	33.75	58.91	0.53	41340
14		6:30 PM-7:30 PM	19.37	14.03	5.93	25.27	31.55	67.77	0.44	70440

* PM concentrations in microgram/cubic meter

It is known that traffic exhausts generate mainly particles in the fine and ultra-fine region. Table 1 shows the different constituents of particulate matter analysed gravimetrically. The average hourly concentration of PM_1 is $24 \pm 6\ \mu g/m^3$; $PM_{2.5-1}$ is $4.9 \pm 1.1\ \mu g/m^3$, where as $PM_{10-2.5}$ are $9.9 \pm 4\ \mu g/m^3$ and TSP–PM_{10} is $11 \pm 7\ \mu g/m^3$. A poor correlation was obtained between particulate matter and environmental conditions like temperature, relative humidity, wind speed, traffic count and hence to ascertain their impact more research is needed in this area.

Figure 2 shows the percentage of different particulate matter out of the total suspended particulate matter gravimetrically over the monitoring period. It is seen that on an average PM_1 comprises $50 \pm 8.6\%$ of the total suspended particulate matter; $PM_{2.5}$ comprises $60 \pm 10\%$; and PM_{10} comprises about $82 \pm 6.7\%$ of total suspended particulate matter.

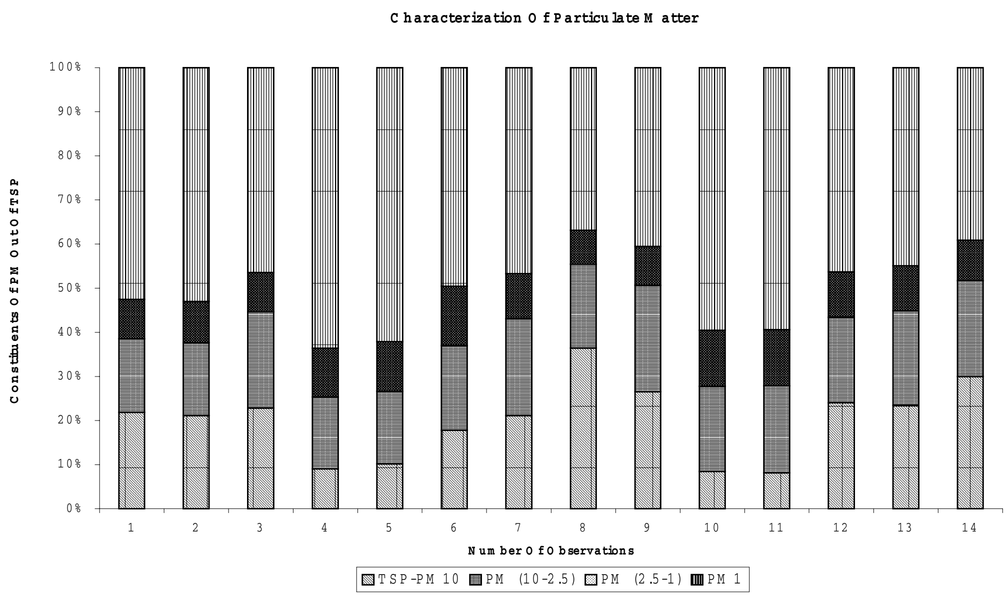

Figure 2 Characterization of Particulate Matter gravimetrically (Note**:** The observation number in graph corresponds to the serial number in Table 1).

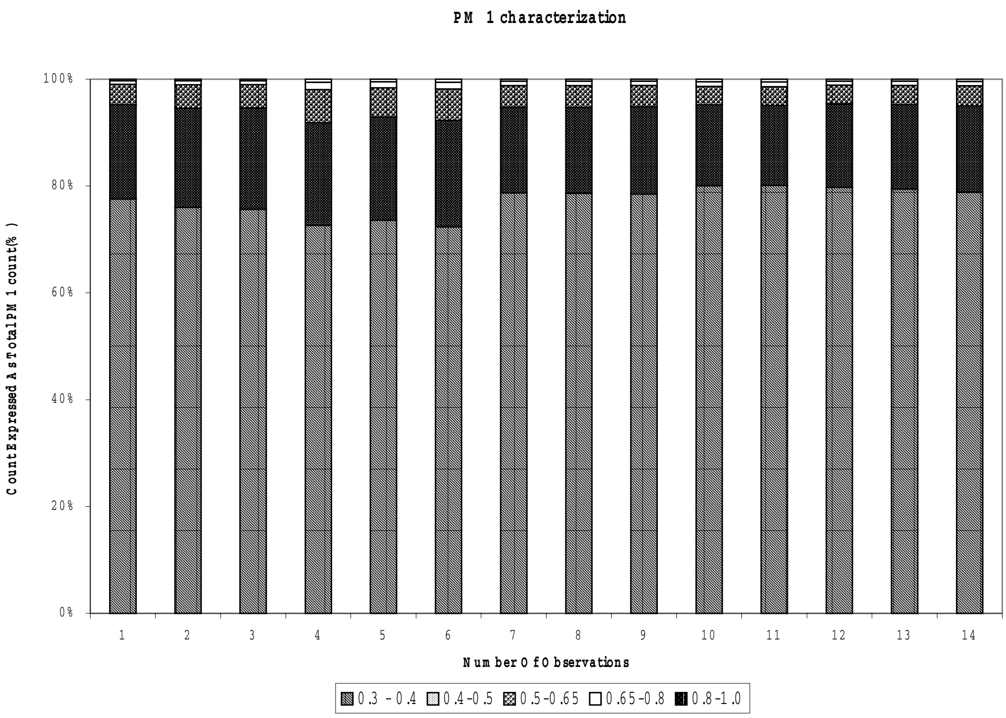

Figure 3 Characterization of PM_1 on the basis of count (Note**:** The observation number in graph corresponds to the serial number in Table 1).

Apart from gravimetric analysis, particles were also characterized on the basis of counts, i.e. counts of particle per litre of air sample. Traffic and combustion-related processes mostly generate particles in the fine region and Grimm Dust monitor can measure particles only up to 0.3 µm size. Hence, ultra-fine particles were not captured by the instrument, though the number would be quite significant. Figure 3 shows the characterization of particles on the basis of number count. It is observed that the number of particle in the range 0.3–0.4 µm is 158208 ± 36775 count per litre of sampled air. It is observed that as the size of particles is increasing their deviation from mean count is also decreasing. For size range 0.4–0.5, 0.5–0.65, 0.65–0.8, 0.8–1.0 µm, the particle count is 34814 ± 8630, 8527 ± 1869, 1747 ± 250, 808 ± 96 count per litre of sampled air, respectively.

Figure 4 shows the characterization of particles in the range of 1–10 µm. It is observed that the particle count in this range is negligible as compared to the fine range. For the size range 1–1.6, 1.6–2.0 and 2.0–3.0 µm, number of particles is 398 ± 82, 236 ± 60, 305 ± 124 particles per litre of the sampled air, respectively. For particle size above 3 µm, it is observed that for 3.0–4.0 µm range, the number of particles is 55 ± 33; for 4.0–5.0 µm, it is 18 ± 11; for 5.0–7.5 µm, it shows 11 ± 6 and only 2 ± 1 particles in 7.5–10 µm size. It is also observed that particle count for PM_1 and $PM_{10\text{-}1}$ is 204,104 ± 45,940 and 1025 ± 310 per litre of sampled air, respectively. PM_1 comprises 62.2 ± 4.9% of PM_{10} gravimetrically whereas 99.5 ± 0.3% countwise (count per liter of sampled air).

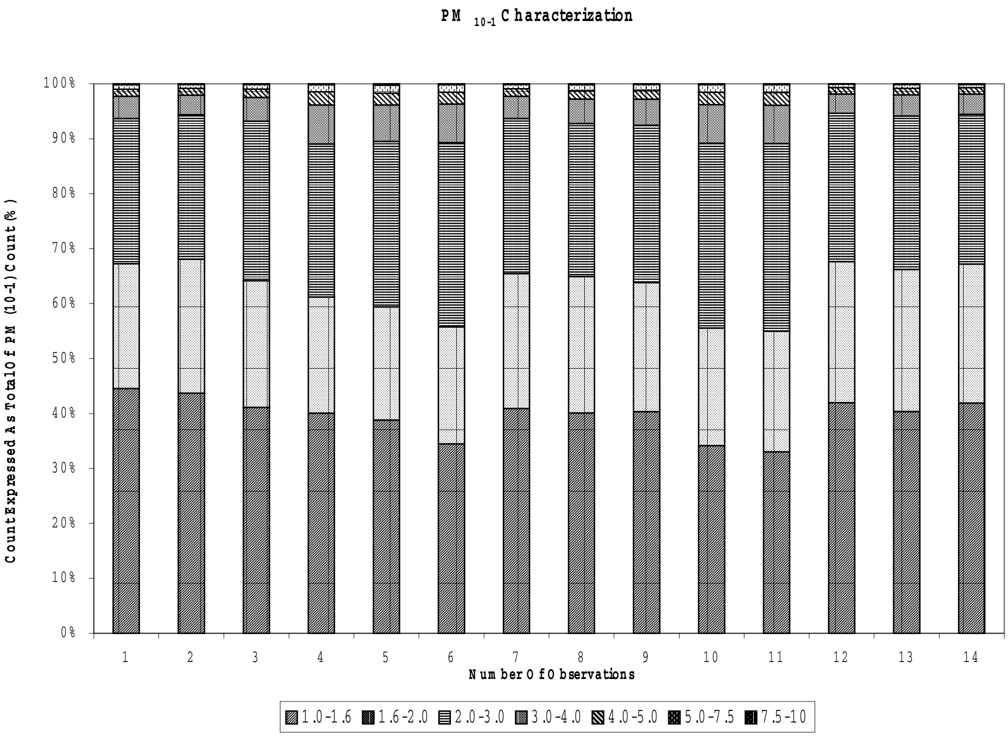

Figure 4 Characterization of PM_{10-1} on the basis of count. (Note**:** The observation number in graph corresponds to the serial number in Table 1).

Though these particles do not contribute much to the weight but they penetrate much deeper into the respiratory system as compared to the larger size particles. Hence, the characterization on the basis of number density is quite significant. The penetration of particulate matter will depend on the size of particles and filtration characteristics of envelope, filtration system of the mechanically ventilated system etc. In addition, the life time and travel distance of fine particles is higher than the coarse size particles. These fine particles contributed to the formation of haze in this region. The behavior of fine particles is complex and hence requires more in depth study.

CONCLUSIONS

The results of this study clearly show that fine particle comprises significantly both in number counts as well as gravimetrically.

- The study shows that 99.5% particles out of PM_{10} are less than 1 μm size.
- PM_{10} comprised almost 80% of the total suspended PM and comprise up to 83% of $PM_{2.5}$ gravimetrically which further shows high proportionate concentration of fine particles.

The study of outdoor environment can help in the selection of fresh air intake locations for the mechanically ventilated buildings to minimize the transport of pollutants inside the building and can also help in filter selection. It is important to assess the migration of pollutant indoors in the wake of all the environmental factors as the fine particles have a greater life span and traveling distance and can induce large amount of toxicity owing to high surface area per unit mass. Further research is necessary to characterize the ultra-fine particles and quantify their effect on the lung function.

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