Investigation on Nano Particulate Aerosol at Idling Conditions of Vehicles

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Abstract. In general, Engine will emit more particulate tailpipe emissions during idling and acceleration conditions. This is a common phenomenon in location such as Toll Plazas which has one of the highest number of vehicle density in urban areas. Therefore the study of aerosol particulates characteristics like average particle concentration and average particle diameter in air is important. The objective of this work is to describe the process of measurement and analysis of ambient Nano Particulate Matter at a Toll Plaza in a Tier II city. A nano particulate counter was used to measure particulate samples and it was mounted at a position that best replicates human exposure to the pollutants. The measurement was carried out for duration of 20 consecutive days and the time of the measurement was planned so as to cover peak traffic time experienced at the Toll Plaza. Particulate number concentration was measured at varying vehicle densities and also at different wind speeds. The results revealed that high concentration was observed for an increase in vehicle concentration as anticipated. Also high number concentration was observed for smaller particulate size (diameter 20 to 80 µm). The relation with number concentration and wind speed was inconclusive.

Introduction

Over two million deaths happen each year due to respiratory system damage caused by air pollution [2]. Among these death due fine particulate matter is 2.1 million [5]. Particle matter in the air can be roughly classified into coarse (diameter ~ 10µm), fine (diameter ~2.5µm) and ultrafine particles (diameter ≤0.1µm). The characteristics of the particle varies drastically with their size. Large particles having diameter around 10µm, stays suspended in air for a few minutes to few hours and has a range of 1 to 10km before settling, while smaller particles having diameter around 2.5µm will stay suspended in air for days to weeks and has a range of 100 to1000km [3, 5]. The sources of particulate matter varies from combustion of oil, gasoline, coal, transformation products of SO₂, NOₓ, metal oxides, dust, fly ash, sea salt and various organic parts [3].

A major contributor to this particulate matter air pollution is from vehicles as tail pipe emission due to the combustion. An ideal engine condition that facilitates particulate formation is vehicle idling. At
idle condition the manifold throttle is only partly open, this creates additional load on engine due to formation of low pressure zone on the underside of the throttle. In addition the volumetric efficiency deteriorates due to blockage of free flow. But during cruising conditions the throttle is at wide open position and thus engine is at high efficiency. Therefore it is logical that high air pollution is observed in areas with high idling vehicle density such as in traffic junctions and toll plazas.

A Toll Plaza was selected within the city limit. The selected Toll Plaza has an average traffic flow of 25000 vehicles on weekdays with an average flow of 58 vehicles per minute. The majority of these are heavy duty vehicles as shown in figure 1. Figure 2 shows the selected Toll Plaza and the surrounding areas. It is to be noted that a hospital and a school were in the exposure range of the particles emitted from this Toll Booth.

![Classification according to vehicle type](image1)

**Figure 1.** Classification according to vehicle type

![Map showing the relevant Toll Plaza and the surrounding areas](image2)

**Figure 2.** Map showing the relevant Toll Plaza and the surrounding areas
Experimental Setup
The Nano Particulate counting system used is a ‘Diffusion Size Classifier Mini’ or ‘DiSC Mini’ from ‘Matter Aerosol’, Switzerland. It has a time resolution of 1Hz and gives the particle count in real time. It has an average particle size range of 10 to 300nm and a concentration range of 1000 to 1000000 particles per cm$^3$. It further has the advantage of being very portable thus allowing the measuring point to be precisely selected.

In order to measure metrological parameters such as Wind Speed, a three cup hand-held anemometer (DHA 111) with a Sampling Time of 2 seconds and accuracy of +/- 3% was used. A standard Thermometer and Hygrometer was used to measure ambient temperature and humidity.

The Plaza had four lanes. Lane 1 catered to traffic towards west, Lane 3 & Lane 4 catered to traffic toward the opposite (East) direction. Lane 2 was kept blocked and was opened only to let emergency vehicles pass through and also when congestion increases in a particular lane. The experiment with all the instruments were mounted on the slightly elevated island between Lane 1 and Lane 2 in front of the Operator’s Booth.

The Particle Counter was placed at a height of 3 meter from the road surface. The anemometer was placed at the same height and two feet away from the counter to get an accurate wind speed without obstructing inflow to the counter.

Methodology
The measurement was taken for a duration of six hours per day for a total of 20 days. The measurement time was designed to cover the peak evening traffic. The time for measurement was taken as 2 to 8 pm.

Results and Discussions

| Time Duration | Average Temperature (°C) | Average Relative Humidity (%) |
|---------------|--------------------------|------------------------------|
| 2pm-3pm       | 33.5                     | 46.8                         |
| 3pm-4pm       | 31.5                     | 46.7                         |
| 4pm-5pm       | 30.4                     | 484                          |
| 5pm-6pm       | 30.7                     | 49.3                         |
| 6pm-7pm       | 29.1                     | 58.2                         |
| 7pm-8pm       | 27.7                     | 67.4                         |
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Table 2. Particle characteristic data along with vehicle data

| S. No. | Time       | No. of Vehicles | Time       | No. of Vehicles | Total Vehicles | Average Particle Concentration (Pt/ccm) | Average Particle Diameter (nm) | Avg LDSA (μm²/ccm) |
|--------|------------|----------------|------------|----------------|----------------|----------------------------------------|--------------------------------|-------------------|
|        |            | Heavy Vehiclen | Four       | Two Wheelers   |                |                                        |                                |                   |
|        |            | 3             | 42         | 8              | 88             | 56433.6                                | 72.2                          | 218.91            |
| 1      | 3 - 3.15pm | 38            | 42         |                |                |                                        |                                |                   |
| 2      | 3.30 - 3.40pm | 41          | 46         | 12             | 99             | 53429.8                                | 68.3                          | 355.8             |
| 3      | 3.40-3.55pm | 42           | 44         | 4              | 90             | 56776                                  | 65.25                         | 273.19            |
| 4      | 4.15-4.30pm | 39           | 30         | 8              | 77             | 41373.6                                | 67.7                          | 254.8             |
| 5      | 4.45-5.00pm | 56           | 73         | 9              | 138            | 62945.9                                | 61.8                          | 425.7             |
| 6      | 5.30-5.55pm | 58           | 50         | 27             | 135            | 48236.5                                | 54.6                          | 276.1             |
| 7      | 6.10-6.30pm | 51           | 34         | 11             | 96             | 49227.2                                | 75.9                          | 260.3             |
| 8      | 6.50-7.15pm | 69           | 42         | 4              | 115            | 58822.9                                | 78.1                          | 352.27            |
| 9      | 7.30-7.45pm | 59           | 34         | 7              | 100            | 63183.1                                | 96.2                          | 497.0             |
|        | Average    | 50           | 44         | 10             | 104            | 54492.1                                | 71.1                          | 323.8             |

Average Ambient Temperature and Relative Humidity values are shown in Table 1 on an hourly basis. This data is measured since Ambient Temperature and Relative Humidity will influence behavior of suspended particle matter. Geometric mean values of Particle Concentration, Particle Diameter, LDSA for an average day is given in Table 2. It also gives the time duration of measurement and the Type and Number of vehicles plying during the specified time period. Table 3 gives the wind speed and the corresponding Particle Concentration. Wind Speed readings above 0.1 m/s is only taken and the values are arranged in the ascending order.

Table 3. Wind speed data

| S No. | Wind Speed (m/s) | Avg Particle Concentration (pt/ccm) | S No. | Wind Speed (m/s) | Avg Particle Concentration (pt/ccm) |
|-------|------------------|-------------------------------------|-------|------------------|-------------------------------------|
| 1     | 0.1              | 49456                               | 14    | 1.4              | 18512                               |
| 2     | 0.2              | 51654                               | 15    | 1.5              | 13715                               |
| 3     | 0.3              | 37594                               | 16    | 1.7              | 20817                               |
| 4     | 0.4              | 7474                                | 17    | 1.8              | 45912                               |
| 5     | 0.5              | 25017                               | 18    | 1.9              | 10277                               |
| 6     | 0.6              | 274184                              | 19    | 2                | 175278                              |
| 7     | 0.7              | 12550                               | 20    | 2.1              | 38885                               |
| 8     | 0.8              | 89741                               | 21    | 2.2              | 10575                               |
| 9     | 0.9              | 24958                               | 22    | 2.3              | 27706                               |
| 10    | 1                | 36070                               | 23    | 2.4              | 26877                               |
| 11    | 1.1              | 71328                               | 24    | 2.6              | 6401                                |
| 12    | 1.2              | 51159                               | 25    | 3.2              | 8785                                |
4.1 Assessing the Potential Impact of the Traffic on the Particulate Level

To assess the impact of vehicle concentration at toll booth on the particle concentration. A graph was plotted between the concentration level and the number of vehicles simultaneously present at the booth. It is seen in the figure 3 that there is a definite increase in Particle Number Concentration (PNC) with increase in the simultaneous number of vehicles. This confirms the fact that vehicles are the major contributing factor to the pollution at the toll booth.

![Figure 3. Variation PNC with no. of vehicle](image)

4.2 Assessing Relationship between Particulate Size and Concentration

Figure 4 shows the size of particles plotted against the particle number concentration (PNC). The entire size range is split into two, the lower half and the higher half. It is seen that 91% of the particles lies in the lower half range (i.e. 0 to 150 nm range).

Also it is seen that the average diameter of the particles is 73nm. This diameter is associated with a PNC of 54702 particles /cm$^3$. This shows the presence of increasingly smaller sized particles in any measured particulate sample. This indicates more focus should be on Ultra-Fine particles. More accurate measuring techniques such as Particle Counting is suggested to be adopted.

![Figure 4. Variation of PNC along with particle size](image)
4.3 Assessing the Potential Impact of Wind Speed in Particulate Level

It was *a priori* hypothesis that with increase in wind speed and relative increase in PNC would also be seen. But it is observed in figure 5 that PNC shows no strict trend along with the rising wind speed. This may be due to the fact that the immediate surroundings of the toll plaza is an open space present with trees. Thus the higher order of wind speed brings with it a mixture of the vehicle pollutants as well fresh air from the surroundings.

![PNC vs Wind Speed](image)

**Figure 5.** Variation of PNC along with wind speed

**Conclusion and Future Work**

a) PNC is seen to increase in relation to vehicle concentration. This confirms the fact that vehicles are a major contributing factor to the nano particulate matter.

b) In terms of relation with size, it is seen that 91% of the total number of particulates are seen to lie in the lower half of the total diameter range (i.e. 91% of particles has a diameter in the range of 0-150nm for a sample with a range of 0-300nm). This show the presence of increasingly smaller particles in the measured sample. This indicates to the importance of measurement of smaller particulates given the fact that as size decreases the danger to humans also increases. In order to get a better understanding of the level of pollutants, particle counting is advised over conventional mass measurement.

c) The relation with wind speed and PNC was studied. No systematic trend was observed. It is suggested to incorporate wind direction data during measurement. To further understand dynamics of such particles with respect to Brownian motion and turbulent diffusion, a controlled environment study such as a wind tunnel is suggested.

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