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Elemental and Organic Carbon in Ambient Air of a Major Indian Urban Community

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Abstract Recent epidemiological studies have demonstrated associations between residential proximity to traffic sources and adverse respiratory symptoms as the Diesel Exhaust Particulate surfaces act as a site for the concentration of thousands of organic compounds. Analysis of 24 h integrated samples of PM10 and PM2.5 collected at a kerb site in a major Indian urban community, heavily impacted by heavy commercial vehicles, showed elemental carbon concentrations higher (14.4–48.8 μg/m^3) than organic carbon (1.7–9.2 μg/m^3). The organic to elemental carbon ratio varied from 0.09 to 0.31. Average concentration of PM10 and PM2.5 ranged 133–492 μg/m^3 and 87–160 μg/m^3, respectively.

Keywords Elemental carbon · Organic carbon · PM10 · PM2.5

The presence of carbonaceous particles in the atmosphere has been implicated by some researchers as having a potential human health impact (Klaassen 1996; Dockery et al. 1993; Schwartz et al. 1996; He et al. 2001; Schwartz 1993; USEPA 1996). Elemental carbon (EC) produced during wood combustion and from diesel engine exhaust can pick up cancer-causing chemicals like benzo(a)pyrene and give them a free ride into our lungs. Thousands of organic carbon compounds in addition to benzo(a)pyrene have been identified in exhaust from vehicles (Hamilton et al. 2004), combustion processes and even meat-cooking operations (Claudia et al. 2009). Combustion aerosol also has a major influence on air quality and is known to have a direct and indirect impact on the Earth's radiative forcing (Mahlman 1997). The surface-rich morphology of Diesel Particulate Matter (DPM) facilitates binding with other toxins in the environment, thus increasing the hazards of particle inhalation. Exposure to DPM has been linked with acute short-term symptoms such as headache, dizziness, light-headedness, nausea, coughing, difficult or labored breathing, tightness of chest, and irritation of the eyes, nose, and throat and long-term exposure symptoms such as cardiovascular disease, cardiopulmonary disease, and lung cancer (Laden et al. 2006). Researchers are therefore becoming increasingly interested in determining the particulate carbon concentration in areas most likely to be affected by human activity-along traffic corridors, in cities, and in other areas with major potential sources of particulate carbon. The Environmental Protection Agency (EPA) established the Clean School Bus USA initiative in an effort to unite private and public organizations in curbing student exposures to DPM as they ride diesel-powered school buses to and from school. The US Department of Labor's Mine Safety and Health Administration (MSHA) established a limit on the concentration of DPM permitted in miners' underground work environment at 160 μg/m^3 TC effective from January 2006 (*Federal Register 66(13): 5706*).

Various techniques are commercially available for determination of carbon in ambient air. The carbon present in the particulate matter sample is thermally converted to CO_2 (at 340–450°C for organic carbon (OC) and 750–1,100°C for elemental carbon (EC)) and subsequently determined by either of the techniques, viz. coulometry,

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non-dispersive infrared (NDIR), conversion to methane followed by flame ionization detection (FID) etc. Continuous online analyzers, such as series 5400 from Rupprecht & Patashnick, sample particulate matter from ambient air for 1–3 h, and then perform an analysis to determine the concentration of OC and EC in suspended particulate matter. Such samplers also have choice of sample-inlets from PM-10, PM-2.5, PM-1 or TSP. Reference material like RM 8785 have been developed for use in the evaluation of analytical methods used to characterize the carbon composition of atmospheric $PM_{2.5}$ for National Ambient Air Quality Standards (NAAQS) monitoring programs (Klouda et al. 2005). National Environmental Engineering Research Institute has been monitoring ambient air particulates (SPM and PM10) in various Major Indian Urban Centers. The PM10 samples collected on glass fiber filter (20 × 25 cm size), with respirable dust sampler operating at 1.5 m^3/min, were analyzed for determination of EC and OC using the internationally accepted coulometric technique based carbon analyzer. In this communication concentration of EC and OC in ambient air of a major urban center and their relationship with PM10 and PM2.5 has been discussed.

Materials and Methods

A Behr model C30IRF coulometric carbon analyzer equipped with infrared and resistance furnaces, and titration vessel was used for the analysis. The minimum detection limit of this analyzer is 1 μg/g. The analyzer was operated in OC/EC mode and the results were noted. Nitrogen (high purity) and Oxygen (commercial grade) gases were used. The analyzer differentiates between "organic" and "elemental" carbon by oxidizing the sample at an intermediate temperature 340°C (default temperature) before conducting a full burn at 800°C.

Discs of 1.5 cm diameter each were punched out of the blank and sampled glass fiber filter. Standard solution was prepared by dissolving 52.48 mg oxalic acid (AR grade and desiccated) in 100 ml distilled water. One ml aliquot of this standard solution reads 100 μg carbon. Ambient air particulate with size range 2.5 μm and below (PM2.5) were collected on Teflon filter (47 mm diameter) with Fine particulate sampler operating at 1 m^3/h. Mass concentration of PM10 and PM2.5 were determined gravimetrically.

The PM10 filter samples were first volatilized/pyrolized in an inert (Nitrogen) atmosphere. To achieve this, IR furnace was programmed so that the temperature of the filter sample rises from 80 to 620°C in three steps, (1) up to 80°C for 20 s at temperature gradient of 500°C/min, (2) up to 340°C for 2 min at 1,500°C/min and (3) up to 620°C for 8 min at 1,500°C/min. The carbon in sample found during this phase is described as OC (Organic carbon). Thereafter, a minimum of 20% oxygen was mixed with the inert gas flow and the temperature was increased up to 800°C for 7 min at temperature gradient of 400°C/min. During this phase, the EC (elemental carbon) remaining on the filter is thus combusted in a controlled manner. The TC (Total Carbon) is the sum of OC plus EC (VDI 2465, Part 1, 1996). The recovery studies were carried out by absorbing known concentration of the standard solution on the PM10 sample aliquot. A recovery of 92–96% for both EC and OC was obtained.

Results and Discussion

Concentrations of PM10 and PM2.5 measured during May 2005 to January 2006 have been presented in Fig. 1. During summer months (May–June) and early monsoon (July) the PM10 concentration was the high (425–520 μg/m^3) and the percentage of PM2.5 in PM10 was the least. This can be attributed to coarse loose soil intrusion into ambient air due to dust raising winds and turbulent atmosphere during these months. During August, the PM concentrations are the least whereas the PM2.5% in PM10 is the most (65%). This shows that most PM in ambient air during rainy season constitutes fine particulates as the loose soil intrusion in the ambient air is the least during rainy season. This high percentage of PM2.5 can be attributed mainly to diesel automobile exhaust emissions near the sampling site. The PM2.5 (%) in PM10, however, starts decreasing during post monsoon and remains in the range 30–40 through winter months. The PM2.5 concentration remained in the range 140–180 μg/m^3 during winter months whereas the PM10 concentration showed sharp rise. This may be attributed to incursion of road dust and contribution from other commercial activities in the area around the monitoring site.

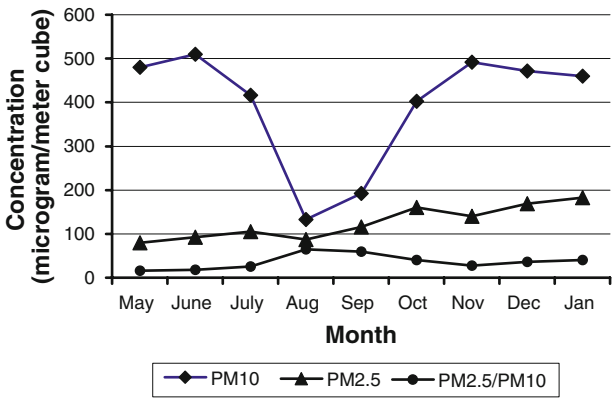

Fig. 1 Monthly average concentration of PM10 and PM2.5 and PM2.5/PM10 ratio

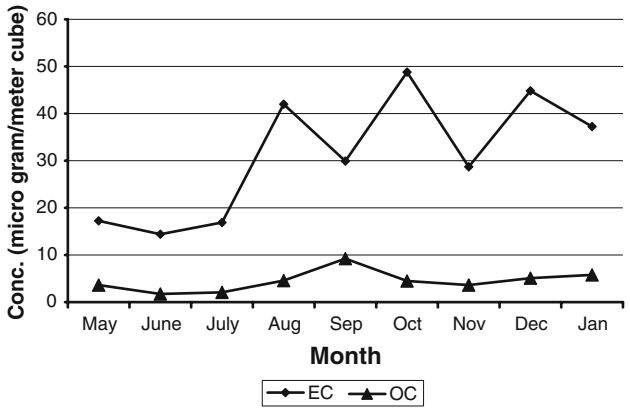

Fig. 2 Monthly average concentration of EC and OC

Variation in EC and OC concentration during May 2005 to January 2006 has been presented in Fig. 2. The concentration of OC ranged from 1.7 to 9.2 μg/m^3 with minimum during June and maximum during September. The EC concentration ranged from 14.4 to 48.8 μg/m^3 with minimum during June and maximum during October. The OC/EC ratio ranged from 0.09 to 0.31 with an average of 0.15, which is lower compared to 1.6–12.8 with an average of 5.2 reported for Mira Loma, USA (Kwangsam et al. 2004). The overall value of the ratio was higher (0.21–0.31) during May and September (clear sunny months during summer and post monsoon) and minimum (0.09–0.15) during the remaining months. Consistent presence of a clear minimum ratio for OC/EC in urban and rural areas, in winter and summer, suggests that samples having the lowest OC/EC ratios contain almost exclusively primary carbonaceous compounds.

The minimum ratios can be affected by various factors such as meteorology, diurnal and seasonal fluctuations in emissions, local sources and long-range aerosol transport (Castro et al. 1999). The overall correlation coefficient between monthly average concentrations of OC and EC is 0.86. The correlation coefficient between monthly average concentration of PM2.5 and EC is 0.24 whereas it is negative (−0.17) between PM2.5 and OC. Seasonal correlation coefficient between EC and OC concentrations is 0.09 during summer months of May and June, 0.86 during monsoon months of July and August, 0.15 during post monsoon months of September and October and 0.08 during winter months of November to January. The seasonal difference in correlation between OC and EC concentrations were attributed in part to significant secondary organic aerosol formation. The strongest correlation between EC and OC occurs during lower photochemical activity (Kwangsam et al. 2004). In the present study, such strong correlation between EC and OC was obtained during monsoon season. Overall, EC and OC concentrations accounted for 20–48% and 3.6–9.2% of PM2.5, respectively. Higher percentage of EC and overall low OC/EC ratio can be attributed to diesel exhaust emissions from heavy passenger bus and commercial truck movement near the monitoring site.

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References

Castro LM, Pio CA, Harrison RM, Smith DJT (1999) Carbonaceous aerosol in urban and rural European atmospheres: estimation of secondary organic carbon concentrations. Atmos Environ 33:2771–2781

Claudia M, Huffman JA, Cubison MJ, Aiken AC, Docherty KS, Kimmel JR, Ulbrich IM, Hannigan M, Jimenez JL (2009) Characterization of primary organic aerosol emissions from meat cooking, trash burning, and motor vehicles with high-resolution aerosol mass spectrometry and comparison with ambient and chamber observations. Environ Sci Technol 43:2443–2449

Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG, Speizer FE (1993) An association between air pollution and mortality in six U.S. cities. N Engl J Med 329:1753–1808

Hamilton JF, Webb PJ, Levis AC, Hopkins JR, Smith S, Davy P (2004) Partially oxidized organic components in urban aerosol using GCXGC-TOF/MS. Atmos Chem Phys 4:1279–1290

He K, Yang F, Ma Y, Zhang Q, Yao X, Chan CK, Cadle S, Mulawa P, Chan T (2001) The characteristics of PM2.5 in Beijing, China. Atmos Environ 35:4959–4970

Klaassen CD (1996) Casarett and Doull's toxicology: the basic science of poisons. McGraw-Hill, New York

Klouda GA, Filliben JJ, Parish HJ, Chow JC, Watson JG, Cary RA (2005) Reference material (RM) 8785 air particulate matter on filter media. Aerosol Sci Tech 39:173–183

Kwangsam N, Aniket AS, Song C, David RC III (2004) Primary and secondary carbonaceous species in the atmosphere of Western Riverside County, California. Atmos Environ 38:1345–1355

Laden F, Hart JE, Eisen E, Davis M, Smith TJ, Speizer FE, Garshick E (2006) Lung cancer mortality in a retrospective cohort of drivers in the US trucking industry. Epidemiology 17:S173–S174

Mahlman JD (1997) Uncertainties in projections of human caused climate warming. Science 278:1416–1417

Schwartz J (1993) Particulate air pollution and chronic respiratory disease. Environ Res 62:7–13

Schwartz J, Dockery DW, Neas LM (1996) Is daily mortality associated specifically with fine particles? J Air Waste Manag Assoc 46:927–939

USEPA (1996) Air quality criteria for particulate matter. EPA/600/P-95/001aF-001cF. Washington, DC: U.S

VDI 2465, Part 1 (1996) Chemical analysis of elemental carbon by extraction and thermal desorption of organic carbon. ICS 13.040.20