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Carbonaceous aerosol emissions from India

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Abstract

Budget estimate for carbonaceous aerosols including black carbon (BC) and organic carbon, emitted from the combustion of various fuels, is very important for regional climate studies. Emission factors for carbonaceous aerosols from bio-fuels and soft coke were determined in a controlled combustion study. The emission factors thus obtained along with those available for other fossil fuels consumed in different sectors have been applied to assess the budget for carbonaceous aerosols from India. Preliminary calculations give a range of 1.6–1.8 Tg of carbonaceous aerosols that include 0.4–1.4 Tg of BC. A major (~80%) portion of carbonaceous aerosols emitted from India is found to originate from the use of biomass for energy as 70–80% of energy requirement in rural India is met by combustion of traditional bio-fuels.

Keywords: Carbonaceous aerosols; Organic carbon; Black carbon; Emission factors; Biomass burning; Bio-fuels; Fossil fuels

1. Introduction

The increasing consumptions of fossil fuels and bio-fuels, i.e., the conventional energy sources, increase the emissions of carbonaceous aerosols, which affect the air quality and regional climate. This increase is more significant in the tropics due to increasing population and changing standard of living. Biomass is a major source of energy in developing countries, particularly India, where most of the energy requirement in the rural sector is met by bio-fuels. Although the per capita usage of the bio-fuels is declining as they are being substituted by more efficient commercial energy sources, but with the increase in population, the total consumption of bio-fuels is still showing an increasing trend (Hall et al., 1994).

Nearly 20 wt% of total suspended particulate matter and up to 80 wt% of fine particles in the atmosphere are carbonaceous species in polluted suburban and industrialized areas (Nunes and Pio, 1993). The dark component of these carbonaceous aerosols often referred to as soot or black carbon (BC) is actually a mixture of graphite-like particles and light-absorbing organic matter (OM) (Andreae, 2001). The magnitude of direct radiative forcing from BC itself exceeds that due to methane, suggesting that BC (0.8 W m^{-2}) may be the second most important source of global warming after CO_2 (1.4 W m^{-2}) in terms of direct forcing (Jacobson, 2001; Hansen et al., 2001). This component also has another important role in the conversion of SO_2 to SO_4^{2-} in the atmosphere via a mechanism involving catalysis on or by elemental carbon particles

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(Novakov et al., 1974; Delumyea et al., 1980). On the other hand, organic carbon (OC), like sulfate aerosols, also shows scattering effect and contributes toward negative radiative forcing (Liousse et al., 1996) and serious health effects (Wolff and Klimisch, 1981). The carbonaceous particles exist mainly in the accumulation mode (with particle diameters $0.1<d<1\,\mu m$) and thus may be transported over long distances (Lelieveld et al., 2001).

The composition of aerosols over India is different from that over Europe and the USA as it has an abundance of BC (Mitra, 2001; Dickerson et al., 2002; Guazzotti et al., 2003). Using the BC data onboard Rown H. Brown, Guazzotti et al. (2003) have found that the carbonaceous aerosols outflow from India and Arabia is normally originated from biomass/bio-fuels burning (74$\pm$9%). The high potassium concentrations of the order of $1\,\mu g\,m^{-3}$ (0.07–1.43$\,\mu g\,m^{-3}$) is found in the aerosols collected over the Indian Ocean (Kulshrestha et al., 2001) during Indian Ocean experiment (INDOEX), which also suggests the strong influence of biomass burning on the atmospheric aerosols as potassium is mainly contributed from biomass burning.

Despite their widespread distribution in the atmosphere, sources of carbonaceous aerosols in the free troposphere are poorly characterized. It is, therefore, important to assess the nature of emissions from combustion of bio-fuels and fossil fuels for estimating the budget of carbonaceous aerosols emitted from India. Assessment of emissions from various fuels commonly used in India requires the evaluation of their emission factors. Very few reports are available to determine the country-specific emission factors for OC and BC using the typical fuel samples covering the complete burning process involving different stages of combustion (Habib et al., 2004; Venkataraman et al., 2005). For the rural energy sources (bio-fuels and soft coke), the emission factors of OC and BC have been determined in the present studies, whereas the emission factors for fossil fuels are obtained from Bond et al. (2004a) and for charcoal production from Cachier (1998). Using these emission factors, efforts have been made to evaluate the preliminary budget estimates for carbonaceous aerosols from India.

2. Experiments and analysis

In this section, we describe our experimental setup that has been adopted for the quantitative measurement of carbonaceous particles being emitted from various fuels (fuelwood, dungcakes, agricultural residues, charcoal and soft coke).

2.1. Experimental methodology

The experimental setup, designed and fabricated at National Physical Laboratory to carry out burning of fuels, consists of a U-shaped chimney, where one end of the chimney rests on the filter support of the high volume sampler (HVS) (see Fig. 1). A Whatmann $8\times10\,in^2$ GF/A filter is fixed on the filter support for the collection of particulate matter. The other end of the chimney is about 25 cm above the burning support. A known quantity of fuel is burnt below the chimney and the plumes pass through the HVS. The chimney is fixed tight on to the HVS to ensure complete deposition of the particulate matter emitted during the burning of the fuel sample. The details of the apparatus are described in an earlier paper (Gadi et al., 2003). A known amount of fuel is kept on a firebrick support with an electric filament mounted on it to initiate the burning of the fuel. Fuels emit smoke as a result of pyrolysis in the initial stage. When the temperature rises enough, it burns with vigorous flames for some time and ends up in smoldering for a few minutes. The three stages, i.e., pyrolysis, flaming and smoldering, together are referred to as combustion. The fuels studied are fuelwood, dungcakes, bagasse, charcoal and soft coke. The burning period during an experiment is generally about half an hour except for coke and charcoal where it takes more than an hour to complete the combustion. Different quantities of bio-fuel (0.05–0.2 kg) were burnt to check for systematic error, if any. Twenty experiments were performed with each quality of fuel and the standard deviation was calculated for each fuel. This burning setup is very similar to the style of cooking or residential heating adopted in rural sector or small-scale industries except that instead of the electric heater plate some stand is used, which keeps the fuel a little raised above the ground. Sometimes in residential cooking the fuel is burnt on the ground between two bricks or in a three-sided fireplace, i.e., a typical Chulha (an earthen stove used for cooking in villages) or in cylindrical fireplace with raised hearth made of a steel mesh and having provision for air inlet beneath it.