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Black carbon: Climate and Health Perspective

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Abstract
Ubiquitous 'Black carbon' released into atmosphere as a product of fossil fuels burning and biomass have significant role in climate system by absorbing and scattering of solar radiation as well as effect human health [cardiopulmonary hospitalization (short- term effect) to chronic respiratory disease (long- term effect)] due to sub-micron size. Its total global emissions are 8 $TgCyr^{-1}$ in 2004, in which maximum contribution is from open biomass burning and fossil fuel combustion. But, shows large variation in emission estimates are due to different sources of emission. Mixing of different component like sulphates, nitrates, organics, dust and sea salt to black carbon, contribute to change in radiative forcing (changes by ~1.4-2). Apart, from warming of the troposphere and cooling of the surface, black carbon is responsible for snow melt, affects cloud cover and life time thereby affects rainfall mechanism, and reduced visibility. Also, act as site for various chemical transformations in the atmosphere, due to nature of porosity and absorption.

Keywords: black carbon, elemental carbon, atmospheric brown cloud, radiative forcing

1. Introduction

Carbonaceous aerosol of optically absorbing part, which is ubiquitous in nature, is called black carbon (BC). The term black is used because ''particulate matter (PM) of constituent of carbonaceous part absorbs solar radiation of all wavelength'' (US EPA., 2012) [11]. BC, entered into the atmosphere after incomplete burning of fossil fuels (coal and diesel) and biomass (deforestation and burning of crop residue) (Cooke *et al*., 1999; Chang *et al*., 2008) [8, 5]. BC is also emitted by air craft and fire in forest. Their residence time in the atmosphere is more than one week; therefore it is transported over the long distance in the atmosphere. Also, residence time is greater during the dry period in respect to wet period. Due to fine size particle and inert in nature chemically, only elimination process from atmosphere is through wet deposition (Babu and Moorthy, 2001) [1]. BC in atmosphere doesn't exist freely, it associated with other aerosol particles such as organics, nitrates, dust, sulphates, and sea salt (Guazzotti *et al*., 2001) [15]. The ''uncertainty of emission of BC is a factor of 2-5 on regional scale and ±50% on global scale'' (Ramanathan *et al*., 2008) [24]. BC has properties to resistant to degradation that's why it is used to track the biomass burning and pollution of soil, atmosphere, sediments, sea water and ice (Schmidt and Noach, 2000)[31]. BC is often paralleled with elemental carbon (EC), but they have some differences. BC is carbonaceous aerosols that absorb visible light and graphitic form of carbon is EC, which engrosses in the visible range and in atmosphere doesn't reduce to carbon dioxide when heated to 8000^0C. So, all EC are BC, however all BC aren't inevitably EC. BC, when mixed with other particles in the atmosphere like sulphates, flyash and others form atmospheric brown cloud (ABC). ABC can be measured by satellite data, surface observation and field observation (Russel *et al*., 1999; Haywood *et al*., 2003; and Ramanathan *et al*., 2007) [29, 17, 25]. Their global emissions are near about 8 Tg Cyr^{-1} (Bond *et al*., 2004) [3] in which 40% from opens biomass burning, 40% from fossil fuels and 20% from biofuels. But, there is large variation in emission estimates of BC has been reported. The sectoral wise global emissions of BC are shown in Figure 1 (a) (US EPA, 2012) [11].

India occupied second position in term of BC emission, when consider world widely, which have emission range in ''1997 is 400 Gg y-1'' (Reddy and Venkataraman, 2002a, b) [27, 28] – ''901Gg y^{-1} in 2011'' (Paliwal *et al*., 2016) [22]. Also, large variation in emission estimates of BC in India has been reported, for example: It has been reported ''1300 Gg y^{-1} in 2001'' (Sahu *et al*., 2008) [30]. Similarly, ''Greenhouse Gas-Air Pollution Interactions and Synergies (GAINS)'' and the ''Speciated Pollutant Emissions Wizard (SPEW)'' reported 500-580 Gg y^{-1} in 2000. This dissimilarity is due to different factor of emission like power plants, biomass, diesel, energy/power, biofuel and others (Bond *et al*., 2013) [3]. The sector wise emissions of BC in India are shown in Figure 1 (b). In developed countries like USA, Europe and UK BC emission is mainly from automobile sector which is equipped with engines of diesel (Bond *et al*., 2013) [3]. In India, BC emission is mainly from domestic sources which are 47% of total and 22% emission from industrial sector of total (Paliwal *et al*., 2016) [22].

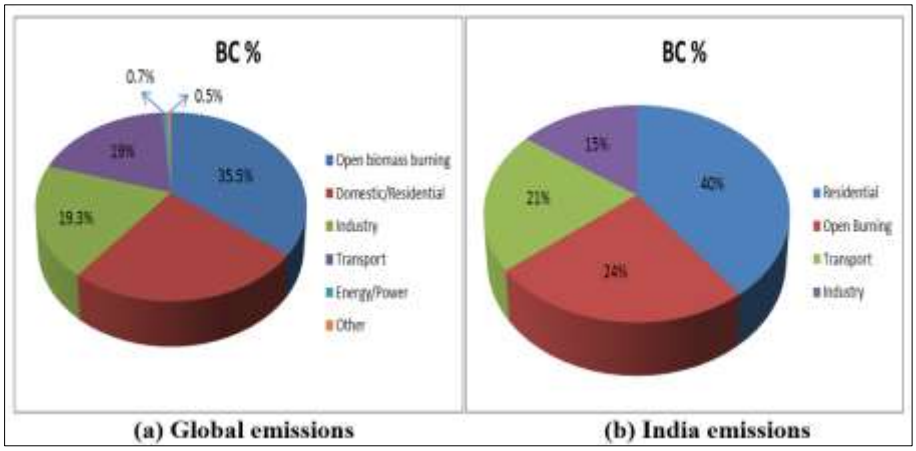
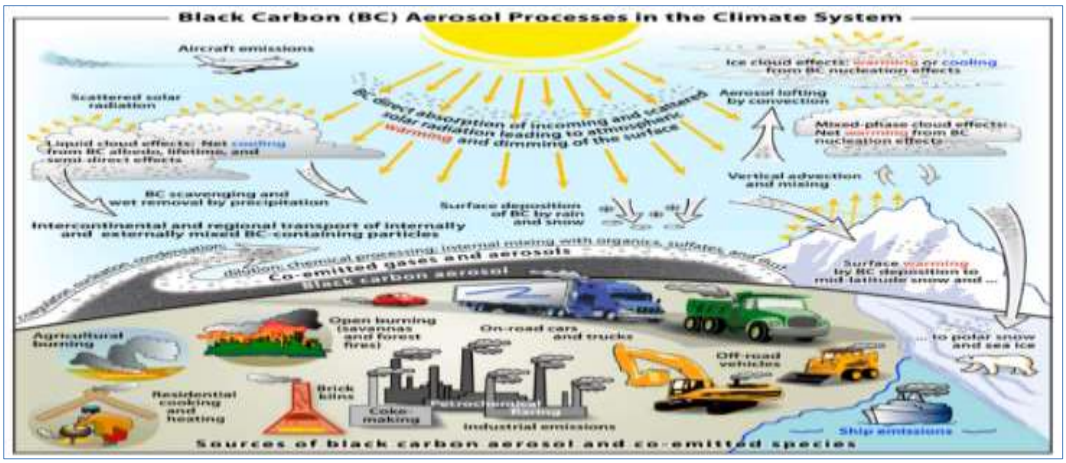


Fig 1: Sector wise emissions of black carbon. (a) Shows Global black carbon emissions (source: US EPA, 2012) [11] (b) shows India black carbon emissions (source: Reddy and Venkataraman, 2002a, b) [27, 28].

2. Climate perspective

Ubiquitous BC particles are significant for climate studies as it has capability to both absorbs and scatter the solar radiation, which causes warming up of the atmosphere and cooling of the surface. BC emitted from incomplete combustion, reduced the amount of solar radiation getting at the earth surface by 10% (Bergstorm *et al*., 2007) [2]. By changing the temperature profile of the troposphere, BC affects the clouds microphysical attributes and thereby mechanism of rainfall (Menon *et al*., 2002) [21]. It has been also reported that BC act as a ''cloud condensation nuclei (CCN)'' when become hydrophilic and thus affecting cloud cover and lifetime (Twomey, 1977) [33]. BC contributes to cloud evaporation when suspended near the cloud, termed as ''semi-direct effect'' (Hansen *et al*., 1997) [16]. Also, it is responsible for snow melt when deposited in snow, after receiving the sunlight (Flanner *et al*., 2007) [13] and then further contributes to warming. It also moderates the visibility of atmosphere (Reddy and Venkataraman, 2000) [26] and point to the presence of combustion particles (Chow *et al*., 2006) [6]. BC has also important role in atmospheric chemistry due to its nature of porosity and adsorption. Due to this, it provides a site for chemical transformation like conversion of nitric acid (HNO_3) vapors to nitic oxide (NO) and nitrogen dioxide (NO_2), oxidation of Sulphur dioxide (SO_2) to sulphate (SO_4) (Disselkamp *et al*., 2000) [10], splitting of Ozone (O_3) and formation of carbon monoxide (CO) (Latha and Badrinath; 2004) [20].

In the atmosphere, increases in BC fractions are responsible to change in surface albedo and Single Scattering Albedo (SSA), which in turn change the sign of Radiative Forcing (RF) of aerosol (Soloman, 2007) [32]. BC change the radiation budget, which have RF estimate to be ''+1.1 (0.17 to 2.1) Wm^{-2}, approximately 65% of CO_2''. Due to mixing of constituents particles (internally or externally) in BC, it has greater effect on RF value (US, EPA, 2012) [11]. It has been reported that RF value is greater by ~1.4- 2, for BC which are internally mixed (Jacobson, 2001; Chung *et al*., 2012) [18, 7]. It has been also noticed that long rang advection of aerosol dust, mixed to BC has large effect on forcing estimate of radiation (Dey *et al*., 2008) [9]. Also, it has been quantified that ''mean value of top of the atmosphere aerosol direct radiative forcing to be 21.5 Wm^{-2} during clean days, escalates to 27.29 Wm^{-2} during normal days and further escalates to 56.56 Wm^{-2} during extreme days'' (Kumar *et al*., 2016) [19] in Delhi region. So, BC emissions, after emission of CO_2 are second chief major contribution to present global warming (Ramanathan *et al*., 2008) [24]. The emissions of black carbon and processes that control its distribution and role in climate system are shown in figure 2.



(***Source*:** Bond *et al*., 2013) [3].

Fig 2: Black carbon emissions, processes that control its distribution and role in climate system

3. Health perspective

'Black carbon' one of the constituents of PM that effects human health badly (Pope *et al*., 2009) [23]. Till date, no any agencies (like public health) addressed the issues of health effect of BC specifically; generally they consider it along with $PM_{2.5}$ (particle matter which has diameter less than 2.5 micro-meters). Research is going on to find out the health effects of BC specifically. Its adverse effects on human health due to its sub-micron size, which can easily reach into the respiratory system. It has both short-term and long- term effect. Its short-term exposure leads to informally linked with death as of ''cardiopulmonary disease, hospitalization and visits to emergency ward for cardiopulmonary problems, increase in symptoms of respiration, reduction in function of lung, and change in physiological symptoms'' (EPA, 2009a) [12]. Also, its contamination in long-term informally linked with death as of ''disease of cardiopulmonary and cancer of lung, and effect system of respiration for example reduction in function of lung or the growth of chronic disease of lung'' (EPA, 2009a) [12]. It is also, used to shows diesel soot in the atmosphere (Fruin *et al*., 2004) [14] and classified as toxic air contaminant.

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