Emissions studies of carbonaceous matter from fuels used in India

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ABSTRACT

The estimation of budget for carbonaceous matter emitted from the combustion of various fuels, is very important for climate studies. In India the main source of energy for cooking and heating is the combustion of traditional biofuels as major percentage of energy requirement in the rural India is met by this source. The emission factors for carbonaceous matter from rural consumption of fuels particularly bio fuels and soft coke have been determined and discussed in this paper. These emission factors along with those available for other fossil fuels consumed in urban industries have been applied to assess the budget of carbonaceous matter emitted from India. Preliminary calculations reveal a maximum of 5 ± 2 Tg of carbonaceous matter which includes 1.3 ± 0.7 Tg of black carbon. 80% i.e. 4 ± 2 Tg of carbonaceous matter emitted from India are found to originate from the use of biomass for energy.

INTRODUCTION

There is an appreciable increase in the atmospheric load of pollution due to the emission of carbonaceous particulate matter, which affects the air quality and regional climate. This is mainly attributed to the increase in the consumption of the conventional energy sources (fossil fuels and bio fuels). This increase is significant in the tropics due to increasing population and changing standard of living in this part of world. Though the main contribution to global warming currently comes from the industrialized nations, the main climate driving force in the current century may, well, come from the energy sources in the developing nations, especially from Asia [1]. Generally this is evident from the rate of increase in the consumption of fuel to meet the annual growth rate of 4% in the electric power. Biomass is a major source of energy in developing countries. The per capita usage of the bio fuels is declining as they are being substituted by the more efficient commercial energy sources, but with the increase in population the total consumption of bio fuels is still showing an increasing trend. Major portion of particulate matter in the atmosphere are carbonaceous species. The dark component of this carbonaceous matter often referred to as soot or black carbon is actually a mixture of graphite-like particles and light-absorbing organic matter [2]. The magnitude of direct radiative forcing from black carbon itself exceeds that due to methane, suggesting that black carbon may be the second most important source of global warming after CO_2 in terms of direct forcing [3]. It is therefore, important to assess the nature of emissions from combustion of bio fuels in addition to fossil fuels for estimating the budget of carbonaceous matter emitted from India. Despite their widespread distribution in the atmosphere, background concentrations in the free troposphere remain poorly characterized. Assessment of emissions from various fuels commonly used in India requires the evaluation of their emission factors. Experimental setup used for quantitative measurements of emissions to evaluate emission factors for various fuels used in the rural sector is described below. The preliminary budget estimates have been worked out for carbonaceous matter based on the emission factors for rural energy sources determined by the authors and taking into consideration the already available emission factors for fossil fuels used in urban/small scale industrial energy sources.

EXPERIMENTAL

Several thermal and wet chemical methods of determining organic carbon and black carbon in the aerosols have been in use [4,5]. None of them is absolute as it is quite difficult to separate the two components because black carbon is a mixture of graphite-like particles and light absorbing organic matter [2]. It was therefore, necessary to develop a method which is simple and quantitative for carbonaceous particles and does give qualitatively the emissions of black carbon (Light absorbing) particles as well as organic carbon (light reflecting) particles The experimental setup has been designed and fabricated at National Physical Laboratory to carry out burning of fuels and the details are discussed in an earlier paper [6]. The fuels studied are fuel wood, dung cakes, bagasse, charcoal and coke. The experiment was repeated several times to get reliable data. This burning setup is very similar to the style of cooking or residential heating adopted in rural sector or small-scale industries except for the difference that instead of the electric heater plate some stand is used, which keeps the fuel a little risen above the ground. Sometimes in residential cooking the fuel is burnt on the ground between two bricks or in a three sided fire place i.e., typical chulha or in cylindrical fire place with raised hearth made of a steel mesh and having provision for air inlet beneath it. Effort has been made to assess the organic carbon (OC) and black carbon (BC) based on the differences in their volatility and combustion properties. The method involves heating a sample in an oxidizing atmosphere progressively to a constant weight and defines OC as the species that are lost by evaporation or oxidation/decomposition completely upto 350^0C in presence of oxygen and BC as carbon oxidized completely at temperature of between 350^0C and 550^0C. The weight loss during the two steps operating at temperatures of 350^0C and 550^0C has been determined gravimetrically to calculate the emission factors of OC and BC from various fuels.

BUDGET ESTIMATES

Quantitative assessment of total carbonaceous matter emitted by fuels is necessary as the extent of absorption of solar radiation by OC quantitatively is not very clear. From the climatic effects and radiative forcing point of view the atmospheric carbonaceous matter (and not so much individual chemical species) is important as both black carbon and fractionally organic carbon are known to absorb radiation. Emission factors of OC and BC for fuels viz., fuel wood, dung cakes, bagasse, charcoal and soft coke determined in the laboratory have been given in table 1. These values represent the emissions in the rural or small-scale industrial sector. The emission factors for biogas, kerosene, LPG, gasoline and diesel have been taken from the literature and are also included in Table 1. It is seen from this table that the emission factors for OC and BC are highest for dung cakes and lowest for LPG with a difference extending to two orders of magnitude. Emission factor for bagasse is used for evaluation of emissions from agricultural residue. The carbonaceous matter emissions depend upon the combustion characteristics and would be smaller with the increase in burning efficiency. The OC and BC emission factors reported in this paper [See Table-1] for charcoal are lower which, may be due to the reason that it may have been subjected to high temperatures during its production and larger amount of the carbonaceous matter is already emitted in the production process. The emission factors for dung cakes are the highest for both OC and EC as observed in the laboratory experiments because dung normally burns under smoldering conditions during its use as a source of energy in rural sector. These results agree with the earlier reports that smoldering fires are more efficient emitters of particles than flaming fires [7,8]. The emission factor is based on the total emissions taking place from beginning to the end representing burning of fuel in the rural sector in India. Emissions during the production of charcoal have also been considered using emission factors given by Cachier, 1998 [4]. Several samples of bagasse have been studied and are assumed to represent the emissions from agricultural waste. Few samples of soft coke have also been studied to evaluate the emissions from their use in the rural areas or in small-scale industries. The emission factors for soft coke (table 1) agree with those reported by Cachier, 1998 [4] but are smaller than 2.78 to 4.55 g/Kg, those of Cooke et al., 1999 [9] for black carbon for consumption in domestic sector The emission factors given by Cachier, 1998 [4] for kerosene and by Reddy and Venkataraman, 2002 [10] for LPG, Gasoline and diesel as shown in table 1 have been used to evaluate the carbonaceous aerosol emissions from these fuels in India. The emission factors for LPG as given by Reddy and Venkataraman, 2002 [10] have also been used for the evaluation of emissions from biogas. An effort has also been made to evaluate their budgets, which requires the consumption data in respect of different fuels.

The total annual consumption of various fuels in rural and urban sectors in India is shown in Table 2. Bio fuel consumption was estimated using per capita consumption at district level and the data has been aggregated at the state and national level for the year 1996-97 [11]. The fossil fuel data includes the consumption of coal/coke, gasoline, diesel, kerosene, LPG and natural gas. For diesel and gasoline the consumption values are for the year 2001-02, however, the data for biogas, coal, kerosene and LPG is for 1996-97 [12,13,14].

Using the emission factors given in Table 1 and the annual consumption of various fuels in India (Table 2), the budget of OC and BC are estimated and presented in Table 3. It is seen from the table-3 that OC (1525±545) Gg and BC (532±266) Gg emissions are higher from dung cakes although its consumption is almost half of the fuel wood used in India. Earlier estimates of Reddy and Venkataraman, 2000 [15] showed that BC emissions from biomass burning for 1990 in India are 0.20 Tg per year. This paper presents the total OC and BC emitted from burning of fuels. The BC emission from fossil fuels is found to be 0.35±0.17 Tg for the year 1996-97 and coal is the biggest contributor from the fossil fuels used in India. Cooke et al., 1999 [9] have estimated BC emissions to be 0.31 Tg for 1984. Reddy and Venkataraman, 2000 [15] had previously estimated BC emissions from fossil fuel consumption to be 0.25 Tg while their revised estimate is 0.1 Tg [10]. The OC emissions estimated by Cooke et al., 1999 [9] from India for 1984 are 0.30 Tg. Our estimate for OC emissions from fossil fuels for 1996-97 is 0.24±0.1 Tg, which agrees in general with the estimate reported by Cooke et al. (1999) [9]. The budget estimates presented in this paper for the various biofuels and soft coke (coal) represent the upper limit of emissions of carbonaceous matter from India. These emissions would be smaller for the part of fuel used in the industrial sector due to higher burning efficiency. These estimates are the indicators of the strengths of the various sources and further work is in progress to carry out measurements on different species of fuel wood, agricultural residues from other crops and varieties of fuel being used as a source of energy in different parts of the country.

CONCLUSIONS

Based on the consumption of fuels in the rural and urban sectors in India, the emission of carbonaceous matter consisting of organic carbon and black carbon is 5 ± 2 Tg and is highest from dung cakes in spite of its lower consumption as compared to fuel wood or coal as a source of energy. This estimate is the upper limit of the carbonaceous matter emissions from India as the emission of carbonaceous matter would be smaller for the fuel used in the urban industrial sector.

ACKNOWLEDGEMENTS

The authors are grateful to Prof. Nupur Prakash, Principal, IGIT and Dr. Bikram Kumar, Director, NPL for their encouragement. Benefit of discussions with Dr. M.K. Tiwari, Head, RAS Division, NPL are gratefully acknowledged. Thanks are also due to Dr. J.C. Sharma and Mr. Deepak Bansal of NPL for technical help.

REFERENCES

1. Crutzen P.J., 2001. Atmospheric Chemistry in the "Anthropocene" Era, Abstracts-Challenges of a Changing Earth, Global Change Open Science Conference, 10th-13th July.
2 Andreae M. O.; 2001. The dark side of the aerosols, Nature, 409, 671-672.
3. Jacobson Mark Z., 2001. Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols, Nature, 409, 695-697.
4. Cadle H. and Groblicki P.J. and Mulawa P.A., 1983. Problems in the sampling and analysis of carbon particulate, Atmos. Env., 17(3), 593-600.
5. Cachier H., 1998. Carbonaceous Combustion Aerosols, in Atmospheric Particles, Ed. Harrison R.M. and Grieken R. Van, 295-348.
6. Gadi Ranu, Kulshrestha U.C., Sarkar A.K., Garg S.C. and Parashar D.C., 2003. Emissions of SO_2 and NO_x from biofuels in India, Tellus B, 55 (3), 787-795.
7. Crutzen, P.J. and Andreae, M.O., 1990, Biomass burning in the Tropics: Impact on Atmospheric Chemistry and biogeochemical cycles, Science, 250, 1669-1679.

8. Cachier H., Liousse C., Pertuisot, M.H., Gaudichet A., Echalar F., and Lacaux, J.P. 1996. African Fire Particulate Emissions and Atmospheric Influence, In: Biomass Burning and Global Change, ed. Levine J.S., 1, 428-440.
9. Cooke W.F., Liousse C., Cachier H. and Feichter J., 1999. Construction of a $1^o \times 1^o$ fossil fuel emission dataset for carbonaceous aerosol and implementation and radiative impact in the ECHAM-4 model, J. of Geophys. Res., 104, 22137-22162.
10. Reddy M. Shekhar, Venkataraman C., 2002, Inventory of aerosol and sulphur dioxide emissions from India: I—Fossil fuel combustion, 36, 677-698.
11. Reddy M. Shekhar, Venkataraman C., 2002, Inventory of aerosol and sulphur dioxide emissions from India. Part II—Biomass combustion, 36, 699-712.
12. TEDDY,2002. Tata Energy Directory and Data Yearbook 2002-2003. Tata Energy Research Institute, Lodhi Road, New Delhi.
13. Mitra A.P. and Sharma C.,2002. Indian aerosols: Present status, Chemosphere, 49,1175 – 1190.
14. Saxena Mukesh, Jain A.K. and Singhal Sudhir, 2002, Indian Auto-fuel policy and its role in Environment, Science & Culture, 68(9-12), 292-302.
15. Reddy M. Shekhar, Venkataraman C., 2000. Atmospheric and radiative effects of anthropogenic aerosol constituents from India. Atmos. Env., 34, 4511-4522.

Bio fuel	**OC (g/kg)**	**BC (g/kg)**	**Reference**
Fuel wood	3.5± 1.9	1.1± 0.5	Present work
Dung cakes	12.6± 4.5	4.4± 2.2	-do-
Bagasse	3.9± 3.4	1.3± 1.1	-do-
Charcoal			
* Production	18	1.4	[4]
* Consumption	0.9± 0.6	0.4± 0.2	Present work
Coke (soft)	1.2± 0.6	0.8± 0.4	-do-
Kerosene	0.5	0.1	[4]
LPG	0.02	0.01	[10]
Gasoline	0.2	0.02	[10]
Diesel	0.0	0.1	[10]

Table 1. Emission Factors for OC and BC from various fuels

Fuel	Consumption (Mt)	Reference
Fuel wood **	302	[11]
Forest biomass**	39	[11]
Dung cakes**	121	[11]
Agricultural waste**	116	[11]
Charcoal*	3	[12]
Biogas*	0.5	[13]
Coal**	285.6	[13]
LPG*	2.1	[13]
Kerosene**	9.6	[13]
Gasoline***	7.9	[14]
Diesel***	52.5	[14]

Table 2: Annual consumption of fuels in India.

* For the year 1990

** For the year 1996-97

*** For the year 2001-2002

Fuel	OC (Gg)	BC (Gg)
Fuel wood	1057±574	332±151
Forest biomass	137±17	43±19
Dung cakes	1525±545	532±266
Agricultural waste	452±394	151±128
Charcoal production	54	4.2
Charcoal consumption	2.7±1.8	2.4±1.2
Biogas + LPG	0.05	0.03
Coal	342.7±171.4	228±114
Kerosene	4.8	1.0
Gasoline	1.6	0.2
Diesel	0.0	8.9
Total	3577±1703	1302±683
Total carbonaceous matter = 4879 ± 2386 ~ 5±2 Tg		

Table 3: Budget estimates of emissions of carbonaceous matter from fuels used in India.