Chemical composition of particles from traditional burning of Pakistani wood species

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HIGHLIGHTS

- Combustion tests were performed with the three most common Pakistani wood types.
- The levoglucosan (LG) content in smoke of tested Pakistani wood types was 5.6%.
- A factor for assessing biomass burning PM from ambient LG was derived.
- The levoglucosan/mannosan ratio in wood smoke ranged from 16 to 28.

ARTICLE INFO

ABSTRACT

Total particulate matter (TPM) emitted during burning of three types of Pakistani wood (*eucalyptus camaldulensis*, local name Safeeda; *acacia nilotica,* local name Kikar, Babul; *dalbergia sissoo*, Shisham, Tali) in a traditional brick stove were collected and analyzed for anhydrosugars, sugar alcohols, trace metals, soluble ions and carbonaceous species. This is a first study reporting anhydrosugars in wood smoke particles emitted during traditional burning of common wood types in Pakistan. Carbonaceous species showed the highest contribution to the particulate matter. Although the total carbon (TC) contribution was similar for all burnings (64.8—70.2%), the EC/OC ratio varied significantly, from 0.2 to 0.3 for Accacia and Dalbergia to 0.7—0.8 for Eucalyptus and Wood-mix. Among inorganic constituents potassium chloride and silicon were found at levels higher than 1%. The levoglucosan concentrations ranged from 3.0 to 6.6% (average 5.6%) with the highest value for Accacia and lowest value for the wood-mix. The high levoglucosan/mannosan ratios of 20—28 were typical for hardwood. The ratio between levoglucosan and galactosan varied stronger and was found to be around 13—20 for Accacia, Eucalyptus and Wood mix, and 43 for Dalbergia. The determined levoglucosan concentrations allowed assessing the conversion factor for calculation of biomass smoke contribution to ambient particulate matter levels in Pakistan.

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1. Introduction

Biomass plays an important role in the energy sector. World-wide 14% of the energy consumption depends on biomass (Demirbas, 2004). In developing countries, biomass is the most important energy source, with 35% share in the energy consumption (Loo and Koppejan, 2002). This number is much lower (~3%) in the industrialized countries, but a growing interest to increase the use of biomass for energy purposes is in line with climate and economic policy worldwide (Loo and Koppejan, 2002).

Model simulation studies indicate a considerable influence of biomass fuel emissions on the atmospheric burden of carbonaceous aerosols in east and south Asia (Bond et al., 2007; Verma et al., 2007). Biofuels, such as wood, straw or dung are commonly used in households for cooking and heating purposes, thus their combustion emissions are the major contributor to carbonaceous aerosols in South Asia (Venkataraman et al., 2005). Air pollution has become a serious problem in developing countries like Pakistan due to its severe health and climate impacts (Parekh et al., 2001).

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Recent studies have revealed that indoor air pollution levels in developing countries can be extremely high due to biofuels combustion and often exceed ambient air quality standards (Smith et al., 2000; Dasgupta et al., 2006; Colbeck et al., 2010; Siddiqui et al., 2009).

The increasing demand of energy has made Pakistan an energy deficient country. According to IUCN (2003) and Rehfuess et al. (2006) 70% of residential energy in Pakistan is provided by biomass combustion, of which 53% is fuel wood. Household Integrated Economic Survey (HIES) were conducted in Pakistan during the years 2001—02, 2004—05, 2005—06, 2007—08 and 2011—12 and according to HIES (2011—12) people spend 20% of their energy expenditure on fuel wood. According to UN Statistics 29,215 thousand cubic meters fuel wood was consumed in Pakistan during the year 2010.

A large number of international studies characterized the nature of particles emitted from diverse biomass combustion systems (e.g. Elias et al., 1999; Fine et al., 2001, 2002; Oros and Simoneit 2001; Rogge et al., 1991, 1993; Schauer et al., 1999; Sheesley et al., 2003; Schmidl et al., 2008a; Stone et al., 2010). However sparse information is available on chemical composition of particle emitted from biomass fuel in South Asia. Only few studies have reported the chemical composition of particles emitted from biofuels commonly used in South Asia (e.g. Sheesley et al., 2003; Zhang et al., 2007). Alam et al. (2014) reported than biomass contribute about 25% of PM10 in urban environment of Lahore Pakistan. Irfan et al. (2014) reported gaseous pollutant emissions from agricultural crop residue combustion in industrial and household sectors of Pakistan while Butt et al. (2013) calculated the biomass and bioenergy potential of fuel wood and biomass in Pakistan. Habib et al. (2008) showed that the burn rate is the most influential factor regarding carbonaceous emissions for a variety of Asian biomass fuels. Li et al. (2007) showed that the size of particles emitted from open burning of wheat, straw and corn stover lays general below 2 μm, based on mass size distribution measurements.

The recent studies of Asian biofuel combustion emissions, including anhydrosaccharide concentrations, concentrate on burning of coconut leaves, rice straw, jackfruit branches, dried cattle dung, etc. However, in Pakistan, next to above listed fuels, also a variety of wood species is commonly burned for heating and cooking purposes, and in brick kiln production. This study was performed to characterize the particle composition during burning of three typical Pakistani wood species in a traditional half-open brick, cooking stove. The focus of the study was directed to the major constituents of the biomass smoke (elemental and organic carbon) and to anhydrosaccharides, which are commonly used tracers for wood smoke in the ambient air (levoglucosan, mannosan, galactosan). In addition, inorganic ions and trace metals were determined to obtain a complete mass balance of measured emissions. The analysis of the saccharidic wood smoke tracers was of interest, since levoglucosan/OC and levoglucosan/PM ratios have been widely used to calculate contribution of biomass combustion in ambient PM samples (e.g. Schauer and Cass 2000; Zdráhal et al., 2002; Puxbaum et al., 2007; Wang et al., 2007; Zhang et al., 2008, 2010; Lanz et al., 2008; Caseiro et al., 2009). In addition, the typical levoglucosan/mannosan ratio, as an indicator for the prevalence of the wood type burnt (Schmidl et al., 2008a), was derived.

2. Experimental setup

2.1. Emission sampling

Three types of seasoned Pakistan wood i.e. *eucalyptus camaldulensis* (local name Safeeda), *acacia nilotica* (Kikar, Babul), and *dalbergia sissoo* (Shisham, Tali) were burned first separately and then as a fuel mixture. Combustion was performed outdoors, at the yard of the Institute of Chemical Technologies and Analytics, Vienna University of Technology, Austria. The cooking stove was made of bricks, in a similar way as it is constructed in most of the rural areas of Pakistan, and is shown in Fig. 1(a) and (b). Three sides were covered with bricks and one side and the top remained open. Each combustion test was conducted with around 1 kg wood logs, which resulted in 5 pieces. All particles emitted from burning process (TPM — total particulate matter) were collected in parallel, via four sampling inlets, each located 1 m above the fire applying three quartz tissue- and one cellulose ester in-line filters for each experiment. Sampling time varied from 23 to 32 min. Size distribution studies for biomass combustion particles (e.g. Lee et al., 2008; Kocbach Bølling et al., 2009; Frey et al., 2009) indicates that majority of particles (80—95%) could be expected in the PM10 range. Thus, although the in-line filter sampling is estimated to enable a collection of sizes up to around 25 μm diameter, our data for constituents in sampled TPM are considered a good proxy for PM10.

2.2. Analytical methods

2.2.1. Weighing and sample preparation

Prior to sampling, quartz fiber filters were baked for 5 h at 550 °C, cooled in a desiccator with water vapor saturated atmosphere, equilibrated for 48 h in an air conditioned room (20 ± 1 °C, 50 ± 5% relative humidity) and weighed with a microbalance (Sartorius M5P with range up to 1 g ± 0.5 μg). The same procedure was repeated with loaded filters. The cellulose-ester filters were only balanced. Loaded filters were stored in the freezer and cut prior to analysis.

2.2.2. Carbonaceous species

Total carbon (TC), elemental carbon (EC) and organic carbon (OC) were measured with a Sunset Lab OCEC Aerosol Analyzer using the NIOSH temperature protocol in the transmission mode. The instrument and method were originally applied for measurements of Diesel soot and described by Birch and Cary (1996).

2.2.3. Saccharides

The determination of levoglucosan, mannosan, galactosan, glucose, arabitol, mannitol and xylitol was performed with high performance anion-exchange chromatography combined with pulsed amperometric detection (HPAE-PAD). The method recommended for atmospheric aerosols was described by Iinuma et al. (2009). Quartz fiber filters aliquots were extracted with 3 ml ultra-pure water (Milli-Q, Milipore), under ultrasonic agitation. The extract was filtered through a syringe filter (0.45 μm, Chromafil, Macherey—Nagel) to remove the insoluble material. Analysis was performed with a Dionex ICS3000 system equipped with a gradient pump, Carbopac MA1 column and electrochemical cell, working with a sodium hydroxide gradient.

2.2.4. Anions

Chloride, nitrate and sulfate were eluted from quartz tissue filters with high purity water (Millipore Milli-Q plus 185). After sonicating and centrifuging, the extracts were analyzed on an AS12A anion-exchange column, with an ASRS Ultra II autoregenerating suppressor, and a model CD20 conductivity cell detector (Dionex).

2.2.5. Cations

Sodium, potassium, ammonium, magnesium and calcium were eluted with 0.1% v/v methane sulphonic acid, which is also the chromatography eluant. After sonication and centrifugation, the