Atmospheric Environment 84 (2014) 189–197

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Estimation and characterization of gaseous pollutant emissions from agricultural crop residue combustion in industrial and household sectors of Pakistan

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HIGHLIGHTS

- Energy crisis has resulted in increased combustion of crop residues in Pakistan.
- Emission attributes of rice husk, rice straw, corncobs and bagasse were estimated.
- Rice straw had significantly higher gaseous pollutant emission factors.
- Bagasse had the highest value of total emission of gaseous pollutants.
- Rice straw and bagasse had >90% share in total gaseous pollutant emissions.

ARTICLE INFO

Article history:
Received 10 July 2013
Received in revised form
14 November 2013
Accepted 18 November 2013

Keywords:
Biomass fuel
Gaseous pollutants
Emission factors
Emission allocations
Emission inventory

ABSTRACT

A long-term energy crisis has resulted in increased combustion of biomass fuel in industrial and household sectors in Pakistan. We report results of a study on the emission characteristics of rice husk, rice straw, corncobs and bagasse since they are frequently used as biomass fuel and differed remarkably in physico-chemical and combustion characteristics. Emission concentrations and emission factors were determined experimentally by burning the biomass fuel using a burning tower. Modified combustion efficiency (MCE) of rice husk, rice straw, corncobs and bagasse was >0.97 indicating that combustion was dominated by flaming mode. Emission factors of gaseous pollutants CO, CO_2, NO_2, NO, NO_x and SO_2 for rice straw were calculated to be 17.19 ± 0.28, 1090.07 ± 24.0, 0.89 ± 0.03, 1.48 ± 0.04, 3.16 ± 0.08 and 0.38 ± 0.03 g kg^{-1} respectively which were significantly ($p < 0.05$) higher compared to those from rice husk (14.05 ± 0.18, 880.48 ± 8.99, 0.19 ± 0.01, 1.38 ± 0.02, 2.31 ± 0.04 and 0.11 ± 0.03 g kg^{-1}), corncobs (8.63 ± 0.12, 595.44 ± 10.38, 0.16 ± 0.01, 0.70 ± 0.01, 1.23 ± 0.02 and 0.02 ± 0.00 g kg^{-1}) and bagasse (12.39 ± 0.08, 937.03 ± 9.07, 0.36 ± 0.03, 1.44 ± 0.02, 2.57 ± 0.04 and 0.18 ± 0.02 g kg^{-1}). Total emissions of CO, CO_2, NO_2, NO, NO_x and SO_2 were estimated to be 3.68, 230.51, 0.05, 0.36, 0.60 and 0.03 Gg for rice husk, 33.75, 2140.35, 1.75, 2.91, 6.20 and 0.75 Gg for rice straw, 1.11, 76.28, 0.02, 0.02 and 0.03 Gg for corncobs and 42.12, 3185.53, 1.22, 4.90, 8.74 and 0.61 Gg for bagasse respectively. Rice straw, however, had significantly ($p < 0.05$) higher potential of gaseous pollutant emission factors. Bagasse had the highest values of total emissions followed by rice straw, rice husk and corncobs. Rice straw and bagasse, on cumulative basis, contributed more than 90% of total emissions of gaseous pollutants. Results reported in this study are important in formulating provincial and regional emission budgets of gaseous pollutants from burning of agricultural residues in Pakistan.

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http://dx.doi.org/10.1016/j.atmosenv.2013.11.046

1. Introduction

Pakistan, with an annual population growth rate of 2.4% and projected population of 18 million people, has been witnessing severe energy crisis over the last five years. At present, approximately 54% of energy requirement is met through fossil fuels such as oil and gas, and rest of the energy is obtained from biomass fuel such as wood and agricultural residues (Tahir et al., 2010). Crop residues are value added organic byproducts generated from harvesting and processing of agricultural crops.

Due to lack of knowledge regarding the significance of crop residues, they are often burned in the field (Samra et al., 2003). Agricultural open field burning is widely practiced in the rural areas and suburbs to dispose of biomass waste (Yevich and Logan, 2003). Several reasons favor burning of crop residue including cleaning and field preparation, meeting domestic energy requirements, fertilizing the field with ash and offering the pest control (Huang et al., 2012; Korontzi et al., 2006). However, the quantity of the crop residues burned and the fire intensity strongly influence the amount of carbon and nutrients released during the fire (Sharma and Mishra, 2001).

Crop residues and/or agricultural wastes are important domestic fuels since ancient times. Nearly half of the world population utilizes crop residues for domestic heating and cooking, especially in developing countries (Guoliang et al., 2008). According to estimates of Andreae and Merlet (2001) and Bond et al. (2004), burning of crop residues accounts for 540 and 475 Tg dry matter combustion per year respectively. Therefore, air quality deterioration, in cities located around major agricultural sectors, is perhaps not surprising (Cancado et al., 2006). There also have been extensive evidence of overlooking the emissions of trace gases from crop residue burning to a large extent, because these fires are often short-lived and do not offer significant time to be detected and quantified under natural conditions (Smith et al., 2007; Vander-Werf et al., 2010).

Field and domestic burning of crop residues consist of pyrolysis, smoldering and flaming processes, however, dominance of these processes and resultant gas emissions largely depend on the type of material being burnt (Andreae and Merlet, 2001). For example, agricultural residues usually follow flaming mode of burning that results in higher NO_x concentrations, dung cakes are burnt through smoldering mode and burning fuel wood normally pass through all three stages of combustion (Saud et al., 2011).

Environmental problems associated with crop residue burning include smoke, trace gases and particulate matter (Bijay-Singh and Yadvinder-Singh, 2003). Concentrations of the greenhouse gases have increased over the past 50 years as a result of anthropogenic activities including agriculture, and have accelerated the rise in average global temperature (IPCC, 2001). In particular, uncontrolled and incomplete open-field burning results in emission of toxic air pollutants and greenhouse gases which affect the atmospheric chemistry (Andreae and Merlet, 2001; Kanabkaew and Oanh, 2011). Agricultural crop residue burning is also the prime source of the micron-sized aerosols which affect the composition of atmosphere (Awasthi et al., 2011; Saud et al., 2011). Trace gases emitted during burning, carbon monoxide and nitrogen oxide, are the main precursors of tropospheric ozone (O_3), decreasing the concentrations of tropospheric hydroxyl radical (OH) (Mauzerall et al., 1998); the later holds potential threats to environment, ecosystem and human health (Cheng et al., 2000).

Emission factor is a crucial parameter used to estimate and quantify emission of trace gases and aerosols from biomass burning which describes compounds or substances emitted per amount of dry fuel burned (Andreae and Merlet, 2001; Yang et al., 2008). Emission factors of gaseous pollutants vary with time and space, and also depend on type, quality and composition of biomass fuel (Shah et al., 1997). Emission factors, measured over longer time periods, are helpful in making emission inventories to control air pollution at local, national and regional levels. Emission factors, from different biomass burning, are integral components for making emission inventories and budgets.

Although studies on emissions from biomass burning are well documented across the globe (e.g. Delmas and Servant, 1982; Lacaux et al., 1993) including studies of Saud et al. (2011) in India and Zhang et al. (2008) in China, the research area is yet to be explored in Pakistan. It should be noted that there are limited emission factors available in developing countries, and those reported in the literature often varied dramatically due to difference in fuel properties and combustion conditions. In addition, emission factors measured in the laboratory may differ from those obtained in field measurements (Roden et al., 2006, 2009; Shen et al., 2010). Therefore, there is need to assess emission characteristics of biomass burning in Pakistan since sever energy crisis have forced large population to use firewood, crop residues and animal dung for meeting energy demands, especially in rural and peri-urban areas.

Keeping in context of the above discussion, a field scale study was performed to evaluate the emission characteristics of commonly burned agricultural biomass wastes in Pakistan i.e. rice straw, rice husk, corn cobs and bagasse. Furthermore, to our knowledge, this is the first study determining emission concentrations, emission factors and emission inventories of trace gases from burning of crop residues in Pakistan. The current study was designed to:

- investigate the emissions of different gaseous pollutants (CO, CO_2, NO_2, NO, NO_x, SO_2) from burning of rice straw, rice husk, corncobs and bagasse.
- characterize and compare the emission factors of rice straw, rice husk, corncobs and bagasse burning
- prepare emission inventories to estimate total emissions of trace gases

2. Materials and methods

2.1. Selection, sampling and preparation of crop residue samples

Rice straw, rice husk, corncobs and bagasse were used in this study because they are burnt in the agricultural fields as waste products and in homes and/or industries for energy in Pakistan. Samples of crop residues were collected in triplicate from farmers' fields and agricultural processing industry around Faisalabad and Kasur in Punjab, Pakistan (Fig. 1). Rice straw and bagasse were collected from Gatwala and corncobs were collected from Jarranwala, suburbs of Faisalabad. However, rice husk samples were obtained from Kasur. Samples were air dried under outdoor ambient conditions for several days before the start of experiment. When uniformly air-dried, samples were kept in sealed plastic bags.

2.2. Construction and design of burning tower

For this experiment, a metallic combustion tower was designed with an aim to facilitate the analysis by channelizing the smoke through one stack (Fig. 2). The tower consisted of an inverted funnel shaped cylindrical bottom having 1.2 m diameter and 1.0 m height. A stack with internal diameter of 0.2 m and length of 1.2 m was attached at the top end of the cylindrical bottom (Fig. 2a). The stack was at 1.2 m height from the ground. The cylindrical bottom was supported with iron rods to keep it at 0.2 m height from ground level (Fig. 2b). A metallic burning table of 0.4 m × 0.4 m dimension was also constructed using a coarse iron wire-gauze which has 0.2 m long legs at its four corners. The stack had an