Atmospheric Environment 125 (2016) 265–271

Contents lists available at ScienceDirect

Atmospheric Environment

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

Field measurement and estimate of gaseous and particle pollutant emissions from cooking and space heating processes in rural households, northern China

Yuanchen Chen[a], Guofeng Shen[a,b,1], Weijian Liu[a], Wei Du[a], Shu Su[a], Yonghong Duan[c], Nan Lin[a], Shaojie Zhuo[a], Xilong Wang[a], Baoshan Xing[d], Shu Tao[a,*]

[a] Laboratory for Earth Surface Processes, College of Urban and Environmental Sciences, Peking University, Beijing 100871, China
[b] Jiangsu Provincial Academy of Environmental Sciences, Nanjing 210036, China
[c] College of Resources and Environment, Shanxi Agricultural University, Taigu, Shanxi 030801, China
[d] Stockbridge School of Agriculture, University of Massachusetts-Amherst, MA 01003, USA

HIGHLIGHTS

- Higher pollutants produced from the space heating compared to cooking process.
- Wood produces highest pollutants, and honeycomb briquette has the lowest emissions.
- Much higher emissions found in the initial phase than the stable phase.
- Higher mass percent of fine particles formed during stable burning phase.

ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form 11 November 2015
Accepted 13 November 2015
Available online 22 November 2015

Keywords:
Solid fuels
Pollutant emission
Cooking
Space heating

ABSTRACT

Pollutant emissions into outdoor air from cooking and space heating processes with various solid fuels were measured, and daily household emissions were estimated from the kitchen performance tests. The burning of honeycomb briquette had the lowest emission factors, while the use of wood produced the highest pollutants. Daily emissions from space heating were significantly higher than those from cooking, and the use of honeycomb briquette for cooking and raw coal chunk for space heating reduces 28%, 24% and 25% for CO, PM_{10} and $PM_{2.5}$, compared to wood for cooking and peat for space heating. Much higher emissions were observed during the initial phase than the stable phase due to insufficient air supply and lower combustion temperature at the beginning of burning processes. However, more mass percent of fine particles formed in the later high temperature stable burning phase may increase potential inhalation exposure risks.

1. Introduction

Solid fuels are worldwide used for residential activities like cooking and space heating in many rural areas of developing countries. Emissions of air pollutants from inefficient solid fuel combustion contribute significantly to both ambient and indoor air quality, and consequent adverse impacts on human health, raising high public concerns (Chafe et al., 2014; Chen et al., 2015; Romieu et al., 2002; Smith et al., 2004). Some previous studies have indicated probable links between exposure to pollution from residential solid fuel use and high mortality and morbidity of respiratory and cardiovascular diseases (Lee et al., 2012; Mishra, 2003; Smith and Mehta, 2003; Zhang and Smith, 2007). Therefore, as a high risk environmental and disease burden factor, household solid fuel use has attracted increasing attention.

To access environmental and health impacts of household air pollution, accurate estimation of emission of combustion products, calculated from fuel consumption amount and pollutant emission factor (EFs), is critically needed. Various kinds of fuels burned for different combustion activities usually result in large variances in pollutant EFs, and pollutant EFs in field measurement can considerably differ from those in well-controlled lab experiments (Dhammapala et al., 2007; Roden et al., 2009; Shen et al., 2013; Zhang et al., 2011). During a whole combustion period, it is perceived that pollutant emissions can vary greatly due to some influencing factors, such as combustion operation, stove temperature and air supply (Carter et al., 2014; Roden et al., 2006). The most

* Corresponding author.
E-mail address: taos@pku.edu.cn (S. Tao).
[1] Present address: National Risk Management Research Laboratory (NRMRL), U.S. Environmental Protection Agency, NC 27710, USA.

http://dx.doi.org/10.1016/j.atmosenv.2015.11.032
1352-2310/

Fig. 1. Pictures for the briquette, raw coal chunk, peat and wood fuels (from left to right) used in the studied area.

notable difference might exist between the initial (including ignition, with relatively lower temperature and insufficient air supply) and stable phases (plenty of air supply, and higher temperature).

While some previous studies have focused on pollutant emissions from the cooking activity, emission measurements for space heating activities, which contributed substantial amounts to total emissions in rural households and cannot be neglected (Chafe et al., 2015), are seldom examined in laboratory or field so far. Therefore, the field works for pollutant EFs (like emission tests) and fuel consumption investigation (like kitchen performance test, KPT) are necessary to obtain reliable information for emission inventory and pollution control.

In this study, field measurements on pollutant emissions including CO, CO_2, PM_{10}, $PM_{2.5}$, elemental carbon (EC), organic carbon (OC) and SO_2 were performed from the burning of different fuels for cooking or space heating. Based on the measured EFs and corresponding fuel consumption through KPT survey, the daily emission amounts of these pollutants from space heating and/or cooking were estimated. According to the real-time emission measured gases, emissions during the initial phase and stable phase were sampled separately, so as to elaborate the dynamic change of pollutant emissions during the whole combustion process. These results are expected to contribute to further stove and fuel intervention programs and field evaluation projects.

2. Materials and methods

2.1. Fuels, stoves and combustion activities

This study was conducted in early March, 2013 in rural Shanxi (Taigu county, Jinzhong municipality) – northern China. Four types of solid fuels, such as honeycomb briquette, raw coal chunk, peat and wood, are commonly found in the studied rural field (Fig. 1). The honeycomb briquette and wood materials are often used for daily cooking, while raw coal chunk and peat are frequently used for space heating. According to the information obtained from the native briquetting plant, the honeycomb briquette is produced from anthracite coal, by compressing raw coal (76%), clay (3%), wood chips (12%), and some other additives, such as $NaNO_3$ (6%), KNO_3 (0.34%), $KMnO_4$ (0.18%) and CaO (0.6%). The raw coal chunk used for space heating is bituminous with volatile matter content larger than 15%, and the peat used is produced from the bituminous coal and clay at a mass mixture of about 1:1. The wood used in this area was the pieces of trunk from elm tree.

Fig. 2 shows the pictures of two typical stoves in this area. The left one is a top-fuelled, small iron stove that often used for daily cooking by burning wood materials or coal briquettes. The other one is relatively large iron stove often for space heating using raw coal chunk and peat. The heating stove is characterized by a bottom-fuelled technology. Both stoves are equipped with outdoor chimneys.

Fig. 2. Pictures of typical cooking (left) and space heating (right) stoves in the studied area.

Emissions for these four different fuels burnt for either cooking or heating activities were measured. A proportion of these fuels were taken back to the laboratory for further analysis of heating value (HV), moisture, contents of carbon, hydrogen, nitrogen, sulfur and oxygen (Table 1).

2.2. Sampling and real-time measurement

In present study, emissions of gases like CO, CO_2, SO_2 and particles (EC, OC, $PM_{2.5}$ and PM_{10}) from residential combustions of coal briquettes and wood for cooking, and raw coal chunk and peat for space heating into ambient air through the stove chimney were measured. Rural residents were asked to conduct the cooking and heating activities as they did in daily lives. As mentioned above, both cooking and heating stoves are equipped with outdoor chimneys. In fact, rural residents often do not want to make a hole in the stove chimney. Therefore, the sampling probe is placed directly near the outlet center of outdoor chimney and also paralleled with the direction of chimney. The dilution system is often used in combustion emission source study, but usually impractical in field study due to its relatively large size causing difficulty in operation and requirement on electricity supply. Therefore, in the present study, we did not use a dilution system. The smoke exhaust is considered to be mixed fast with ambient air, in which high temperature and relative humidity (RH) is considered to be not a major issue in sampling. The measured temperature and RH (Temperature & Humidity Meter, DT-625, CEM, Shenzhen, China) were 47 ± 9.3 °C and $56 \pm 14\%$, respectively, falling into the conditions often required in stationary emission source sampling