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A laboratory based comparative study of Indian biomass cookstove testing protocol and Water Boiling Test

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ABSTRACT

The study was carried out to compare the cookstove performance using Water Boiling Test (WBT) and the Indian Standard on Solid Biomass Chulha Specification developed by the Bureau of Indian Standards (BIS) for testing cookstove. Additionally, the testing guidelines pertaining to feeding interval and ignition material were also tested in the BIS and WBT, respectively. Two cookstoves manufactured by Phillips, Philips Natural Draft (PN) and Philips Forced Draft (PF) were selected for assessing their performance. The thermal efficiency (TE), emission factors (EFs) of carbon monoxide (CO) and particulate matter (PM) were used as performance indicators to compare the cookstove performance. It was observed that both the cookstoves gave comparable TE with no significant difference ($p > 0.05$) using both protocols; whereas, CO EFs were ~39% and ~47% higher in BIS test due to dominance of smoldering conditions compared to WBT in PF and PN cookstoves, respectively. On the contrary, PM emissions were found to be ~55% lower in BIS test compared to WBT in PN cookstove, which could be due to the oven dried wood recommended in the BIS test. Inclusion of emissions of ignition phase was found to increase the total PM and CO emissions during cold start by 45–70% when mustard stalks were used as kindling material compared to wood chips and kerosene. Average CO emissions were found to increase by ~68% and ~48% in PF and PN cookstoves, respectively, with 15 minute fuel feeding interval in BIS test. The result shows that change in combustion conditions during the two different test protocols did not affect the energy parameters; however, the effect on CO and PM emissions was significant. It can be concluded that multiple testing methods might yield different information of cookstove performance leading to difficulty in assessing the actual performance of cookstoves.

Introduction

The use of biomass such as dried cow dung cake, wood and crop residues in rural households in most of developing regions of the world, is the main reason for household air pollution (HAP). Developed countries also have HAP, generally less, and from a variety of sources. The Global Burden of Disease study has recently shown that 7% of the global disability adjusted life years can be attributed to HAP (Lim et al., 2012). According to the WHO (2006) and World Bank (2011) reports, the premature death of around 2 million people worldwide can be directly linked to HAP due to burning of solid biomass fuels such as wood, animal dung and crop residue in traditional earthen cookstoves. Exposure to HAP has been linked to various diseases such as acute lower respiratory infection in children (Bates et al., 2013; Smith et al., 2000); cardiovascular diseases and cataracts in adults especially women, lung function decrement, interstitial lung disease, and respiratory symptoms such as nasal discharge, cough, shortness of breath, and chest tightness (Khalequzzaman et al., 2007). Besides health effects, emissions from biomass burning in cookstoves act as a key source of pollutant species which act as precursors of climate change (Bond et al., 2013; Grieshop et al., 2009).

The clean and efficient cookstoves (CECs) have been promoted through various cookstove dissemination programs in various countries including India. Various initiatives have been taken at an international level like the Global Alliance for Clean Cookstoves (GACC, 2011) and at national level such as National Biomass Cookstove Initiative (NBCI, 2009) in India. The overall aim of these initiatives was to disseminate CECs in rural households that are dependent on biomass based cookstoves (Lewis and Pattanayak, 2012). A large number of cookstoves have been fabricated till date which claims to be more fuel efficient and less polluting. Along with the advent of CECs, various cookstove test protocols were also developed in order to assess the degree of improvement in these new cookstove technologies. The Water Boiling Test (WBT) is an international test protocol which was developed in 1982 by Volunteers in Technical Assistance (VITA, Volunteers in Technical Assistance, 1982), with an aim to provide a set of guidelines to test cookstoves with a standardized procedure.

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The protocol was updated several times by different institutions over the years. In 2007, WBT version 3.0 was developed after certain conceptual improvements, while the latest version was published in the year 2013 with an integration of guidelines for emission testing along with testing of thermal parameters (WBT, Version 4.1.2) (WBT, 2009 & 2013). However, the foundation of WBT was laid down back in 1965 when an Indian Standard test method (IS, Indian Standard: 2994, 1965) was developed for electric stoves. The first test protocol for biomass based cookstoves was developed in 1980 by Intermediate Technology Development Group (ITDG) Reading, England. However, in India the first protocol for testing biomass based cookstoves was developed in 1991 by Bureau of Indian Standards (BIS) titled as "Standard on Solid Biomass Chulha Specification" (IS, Indian Standard: 13152, 1991) and it has not been updated till date. The literature available on cookstove testing indicated WBT as the most widely used test to compare performance of different cookstoves (Ballard-Tremeer and Jawurek, 1996; Bhattacharya et al., 2002; Jetter et al., 2012; Venkataraman and Rao, 2001). However, it can be inferred from the literature that cookstove performance assessed with the help of WBT is not representative of the actual field conditions (Bailis et al., 2007; Berrueta et al., 2008; Boy et al., 2000). Therefore, testing the performance of a cookstove is a challenging task as there are many factors that affect the cookstove performance; for instance, the fuel properties and skills of the tester (Abeliotis and Pakula, 2013; Arora et al., 2013; L'Orange et al., 2012; Roden et al., 2009). Another factor that has been considered to affect the cookstove performance is the "burn cycle" demonstrated by Johnson et al. (2009). The 'burn cycle' refers to a specific pattern of fluctuation in power levels during a cooking process. Therefore, if the burn cycles vary due to the methodology adopted in different protocols the performance of the cookstove might also change with change in combustion conditions. Recently, an international forum on clean and improved cookstoves drafted a "Lima Consensus" and rating system for cookstoves was proposed. Following the consensus International Organization for Standardization (ISO) has signed an International Workshop Agreement (IWA) in order to set benchmarks to assess the performance of cookstoves (IWA, International Workshop Agreement, 2012). Under this assessment, the results of any cookstove test protocol can be compared on a common platform. However, this comparison would only be possible when variables such as fuel characteristics and burn cycles, are identical in any protocol which is used as an alternate to WBT. Therefore, the purpose of this study is to assess the variability induced in cookstoves performance, while testing cookstoves using different protocols (WBT and Indian Standard for cookstove testing). The two protocols were also addressed individually to study the effect of three kindling materials during WBT and two fuel feeding intervals during BIS test on the cookstove performance.

Material and methodology

Stoves tested

Two CECs manufactured by Phillips, namely the Philips Natural Draft (PN) and the Philips Forced Draft (PF) were selected for assessing their performance using two testing protocols as shown in Fig. 1. The PF cookstove comes under the advanced cookstove category. The PF cookstove works as a "quasi-gasifier" cookstove where the injected air (both primary and secondary) allows adequate mixing of air and combustible gases leading to complete combustion of fuel (Anderson et al., 2007). The PN cookstove works on the similar principles however, the supply of air (both primary and secondary) is due to natural convection of air inside the combustion chamber. The combustion chamber of the PN cookstove was metallic inside compared to the PF cookstove which has a refractive material as lining of the combustion chamber, which reduces heat loss during the combustion process through cookstove body.

Fuel used

The most commonly available and used fuel was chosen, which was found to be *Acacia nilotica* in the study area i.e. Delhi city and nearby areas (refer Arora et al., 2013, for more details). The moisture content of the fuel was determined by oven-dry method and it varied from 6% to 12%. The average size of the wood pieces was 2 × 3 × 10 cm, as per the specifications of the cookstove manufacturer. The calorific value of the fuel wood was calculated using a bomb calorimeter and was found to be ~20.9 MJ/kg.

Experimental setup

The testing of cookstoves was performed in the combustion laboratory at TERI University. Sampling was conducted using 'Hood method' and a schematic diagram of the setup is presented in Fig. 2. The experiments were conducted in 5 replicates and consistency in cookstove operation was maintained throughout. The isokinetic conditions were maintained by controlling the draft in the dilution tunnel for taking representative samples of particulate matter (PM) using EPA Method 1A (EPA, 1994). The carbon monoxide (CO)

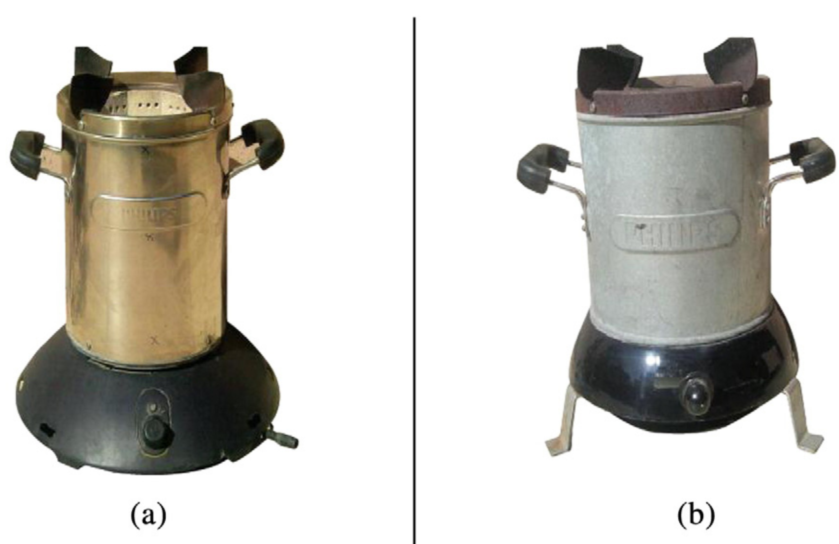

Fig. 1. Photographs of the cookstoves tested.