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Laboratory based assessment of cookstove performance using energy and emission parameters for North Indian cooking cycle

Pooja Arora [a], *Suresh Jain* [a,b,*], *Kamna Sachdeva* [a]

[a] Department of Natural Resources, TERI University, 10, Institutional Area, Vasant Kunj, New Delhi 110070, India
[b] Department of Energy and Environment, TERI University, 10, Institutional Area, Vasant Kunj, New Delhi 110070, India

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ABSTRACT

The study was conducted to evaluate the performance of cookstoves using controlled cooking test (CCT) with cooking cycles of Northern India, i.e., Uttar Pradesh (UP) and Uttarakhand (UK). Cooking time, specific energy consumption (SEC), and emission factors (EFs) of carbon monoxide (CO) and particulate matter (PM) were monitored for three improved and one traditional cookstoves. Cooking was conducted by residents of the study area. The findings from the study showed that the difference in thickness of roti baked in UP and UK resulted in a significant change in emission and energy performance in all the four cookstoves. The low-power inputs required for baking thinner roti resulted in higher CO and PM emissions in case of CCT-UK. The results of CCT were also compared to Water Boiling Test (WBT) for all the four cookstoves. The percent reductions in terms of energy and emission parameters in the three improved cookstoves compared to traditional cookstove were found to differ in CCT and WBT. Large variations were also observed during the emission performance (40% decrease in CO EF) of the fan cookstove with change in fan speed, which was usually unreported in previous studies. Overall, results show significant influence of cooking cycles on cookstove performance, which was found to alter the cookstove rankings. Therefore, the study thrusts upon the inclusion of user centric cookstove testing protocols in order to identify actual benefits for targeted rural communities.

1. Introduction

In most of the developing countries, biomass based cookstoves are a lifeline of any rural household, given the limited financial resources. These bottom of the pyramid (BoP) energy systems are being regularly redesigned and tested, in order to provide the underprivileged sections of the society, a healthy and sustainable lifestyle [1]. Testing of cookstoves is one of the most crucial steps in any cookstove dissemination program. Cookstove testing is conducted in a laboratory, and/or in field conditions, to assess the performance in terms of fuel savings (energy efficiency) and environmental parameters, i.e., emission of air pollutants. Particulate matter (PM) and carbon

* *Corresponding author*. Department of Natural Resources, TERI University, 10, Institutional Area, Vasant Kunj, New Delhi 110070, India. Tel.: +91 11 2612 2222; fax: +91 11 2612 2874.
E-mail addresses: sureshjain_in@yahoo.com, sureshj@teri.res.in (S. Jain).
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monoxide (CO) due to their relevance in terms of health and climatic impacts are the most commonly studied indoor pollutants [2,3]. The most widely used laboratory test is the Water Boiling Test (WBT), which is a simulation of actual cooking style. The latest version of WBT (Version 4.1.2) provides a methodology to test energy efficiency and emissions simultaneously, in order to understand the trade-offs that exist between these two parameters [4]. Under the Household Environment and Health (HEH) Project, two more testing protocol were developed apart from WBT, namely, Controlled Cooking Test (CCT), and Kitchen Performance Test (KPT). CCT and KPT give a better representation of cookstove performance because of the direct involvement of the beneficiaries. Some CCT and KPT based studies have evidently shown a weak link between the actual and simulated cooking conditions [5–10]. These studies have relied on either fuel savings or emission reduction to assess the cookstove designs. However, for a better assessment, energy and emission parameters should be monitored concomitantly. Besides the understanding of these factors, region specific cooking regimes are also crucial part for the cookstove testing [11]. WBT has also been used to associate the cookstove performance with different variables such as fuel and vessel characteristics [12–14]. These variables are representative of varied field scenarios, and the individual impact of these variables can be better understood under controlled laboratory conditions. The concept of 'burns cycle' or 'cooking cycle' introduced by Johnson et al. [15] and has been considered as a critical factor in assessing the actual performance of cookstoves. CCT can prove to be a better method for testing cookstoves as it can easily capture the intricate details of cooking cycles, which can help both stove designers and researchers engaged in development of cookstove testing protocols. In the best of the author's knowledge, no study has been carried out for Indian conditions, where energy and emissions from cookstoves have been reported using regional cooking cycles except one study conducted in Tamilnadu by MacCarty et al. [16]. Therefore, this study proposes to assess cookstove performance in terms of energy and emissions based on 'Indian cooking cycles. These results would be able to measure the variations in cookstove performance using CCT protocol, owing to the difference in cooking cycles existing in two different regions of northern India i.e. Uttar Pradesh (UP) and Uttarakhand (UK).

2. Methodology

2.1. *Cookstoves tested, and test fuels used*

The cookstoves selected in the study are among some of the popular designs available in the Indian markets as shown in Fig. 1. The four cookstoves differed from each other in terms of the build material, size of the combustion chamber, fuel feeding style and source of air supply (fan/free convection). The top feed forced draft cookstove manufactured by Philips India Limited, was selected under the advanced cookstove category. The top feed natural draft (manufactured by Philips) and front feed natural draft (manufactured by Envirofit International Limited) were selected under improved cookstove category. However, for the ease of discussion the above mentioned cookstoves would be denoted as "improved cookstove" in the rest of the paper. The improved cookstoves were tested against a commonly used traditional brick-mud cookstove (front feed mud cookstove, TR) design used in Northern India. The TR cookstove was fabricated in the laboratory on a metal sheet in order to make it portable for the ease of testing. Although in some areas within the study region, double pot cookstoves are also used. This study, however, is limited to single pot cookstoves.

All the tests were conducted using one wood, i.e., *Acacia nilotica* (commonly known as Keeker), which is the most commonly used wood for cooking at testing site. It was also observed during the survey that *A. nilotica* was also found to be common cooking fuel in UP, in combination with other biomass fuels such as cow dung and crop residue. During the survey conducted in UK, the frequently used wood has been oak (*Quercus leucotrichophora* and *Quercus semecarpifolia*); however, past studies have shown that the performance of cookstove more depends on cookstove designs rather than wood types, except hardwoods and softwoods [17]. The wood size used in each cookstove was set according to the manufacturer's product manuals. The wood size for the two top feed cookstoves (PF and PN cookstoves) was 2 × 3 × 10 cm and 1.5 × 1.5 × 25 cm for the EN cookstove and 3 × 3 × 25 cm for the TR cookstove. The wood moisture mass fraction during the testing period was 8–14% (wet basis) measured using oven method, which is also the case in the field. The dry seasons in northern India can last upto nine months including winter and summer during the which the fuel moisture can vary from ≤5% to ≤15%. The wood moisture can vary under different relative humidity and temperature conditions also demonstrated by Simpson and TenWolde [18]. The calorific values for

Fig. 1 – Photographs of the cookstoves tested. (a) Philips forced draft (PF), (b) Philips natural draft (PN), (c) Envirofit front feed (EN), (d) Traditional brick-mud cookstove (TR).