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Research paper

# Evaluation of the performance of improved biomass cooking stoves with different solid biomass fuel types

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ABSTRACT

We have studied the performance of different types of improved solid biomass cookstoves (Two natural draft and one forced draft) in comparison to the traditional cookstove (control) while preparing a particular meal with a variety of solid biomass fuels (e.g. fuel wood, dung cake and crop residue). Five replicates of each type of cookstove and fuel were maintained. The study was conducted in an Indian rural kitchen. There was no significant difference in the indoor concentrations of $PM_{2.5}$ and CO when natural draft and traditional cookstoves were used with any type of solid fuel. However, significantly lower concentrations of $PM_{2.5}$ and CO were recorded with forced draft stoves compared to others. While cooking with different types of solid biomass fuels, the concentrations of $PM_{2.5}$ and CO in the indoor environment were decreased by 21–57% and 30–74% respectively with the forced draft cookstove in comparison to the traditional cookstove. The fuel consumption, cooking duration and thermal efficiency of a particular stove to prepare a particular amount of food also differ depending on the type of the solid fuel used for the cooking purpose. The thermal efficiency of traditional, natural draft and FD cookstoves were in the range of 15–17%, 16–27% and 30–35% respectively for different types of solid biomass fuels. However, further studies on the performance of stoves are required based on the size and type of fuel wood or crop residues.



## 1. Introduction

Consumption of the solid biomass fuel for the domestic cooking and space heating is an important source of atmospheric pollutants which lead to local or global climate change vis-à-vis adverse chronic effects on human health. Inefficient burning of the solid biomass fuel releases large amount of pollutants like particulate matter (mainly $PM_{2.5}$), black carbon (BC), Organic carbon (OC), carbon monoxide (CO), oxides of nitrogen ($NO_x$), sulphur dioxide ($SO_2$), ammonia, benzene, formaldehyde etc. [1]. Among these gaseous pollutants, incomplete burning of the solid biomass fuel is the major source of CO [2]. These pollutants are closely associated with several pulmonary, cardio-vascular, retinal and dermatological diseases [3] and exposure to CO in particular may incur tissue hypoxia in the babies in the womb. The median diameter of the particles emitted during the burning of solid biomass fuel in the cookstove is in the range of $PM_{2.5}$ [4]. It is reported that the $PM_{2.5}$ can travel deep into the respiratory system [5], as a result the exposure to the $PM_{2.5}$ alone has accounted for 3.1 million deaths and around 3.1% of global disability adjusted life years during 2010 [6]. Moreover, the burning of the solid biomass fuel in the domestic kitchen is liable for about 1.6 million deaths per annum [7].

However, solid biomass fuel is still an important source of energy for domestic cooking and space heating. It provides more than 11% of the total energy demand of the world [8,9]. It has been estimated that about 3 billion people in the world use the solid biomass fuel for cooking purposes [10]. More than half of this population resides in the rural areas of the developing countries. Villagers in the developing countries use the solid biomass like twigs, wood, shrubs, crop residue, animal waste or dung etc. to meet their heating and cooking energy need. Traditionally, such biomasses are burnt in a low efficient crude combustion device like the three-stone fire stove to get the required energy for cooking. The burning efficiency of this type of stove is very low and releases large amounts of harmful pollutants due to incomplete burning of the solid biomass fuel. On the other side, the three-stone fire stove consumes large amount of solid biomass due to its low burning

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efficiency which may additionally lead to deforestation and soil erosion. However, immediate shift from solid biomass cooking fuels to so called modern fuel is far away dream as the international price of Liquid Petroleum Gas (LPG), will continue to increase faster than rural incomes and large governmental subsidy on LPG for the rural areas will affect the annual budget of the country.

Worldwide, attempts have been made since 1940 to improve the performance of the solid biomass cookstoves. The improved cookstove consumes less amount of the solid biomass fuel following its high efficiency of burning. This not only improves the health and livelihood of the user but also mitigate the climate change by reducing the amount of emission of different atmospheric pollutants and decreasing the burden on the forest [11]. Failure in the performance of the improved cookstoves in the preliminary phases attributed to lack of testing, incompatibility in the opening of the stove and size of cooking pots, lack of research on burning physics and stove engineering etc. So far, the Chinese National Cookstove project during '90s is the most successful project in this aspect [12]. UNDP and World Bank have funded several improved cookstove projects in different countries during last 4 decades. However, till date, only 25% of the solid biomass fuel users have access to improved cookstoves [13].

Solid biomass fuel accounts for more than 80% of total fuel used for domestic cooking in India [14]. Fuel wood, dung cake and crop residue are the primary cooking fuel for about 90% of solid biomass fuel using households of the country [14]. In India, burning of the solid biomass fuel accounts for more than half a million of premature deaths, 4% of total greenhouse gas emission and more than 30% of total BC emission per annum [15]. The improved cookstove project was first launched in India during 1985 (National program on improved chullah). However, lack of formal scientific monitoring made it difficult to evaluate the performance of different designs of cookstoves [16]. During 2009, the government of India has launched the National Biomass Cookstove Initiatives with a revised standard for stove design and large number of test centers all over the country [17].

Dozens of organizations have developed projects to promote cookstoves as health interventions since the mid '90s in India, but only a few organizations have been able to scale up beyond few thousand stoves [18]. These numbers are impressive, but are not sufficient to impact public health at the large population scale of the country. More recently, large commercial manufacturers such as TARA, Envirofit (Rocket stove), Philips (forced stove) and many other smaller organizations have introduced stove models, based on improved designs and materials, that claim better performance on thermal and ecological factors following the standard set by the government of India [19]. However, commercialization of cookstoves raises important questions about the appropriateness of different models of service delivery when public health and global environment is at stake. The comparison of different improved cookstove models based on standard testing protocols is necessary to estimate the performance of different technologies in compared to the conventional one [20].

Studies suggested that the improved cookstoves may be able to reduce the solid biomass fuel consumption by 19–66% [21]. A controlled study of different cookstoves reported that the fuel consumption in rocket-type stoves was reduced by 33% compared to the traditional cookstoves; while the CO and PM emissions were reduced by 75% and 46% respectively, as compared to the traditional cookstove [22]. While, some TLUD-type forced draft cookstoves recorded 40% reduction in fuel consumption and 90% reduction in PM emission compared to the traditional cookstoves [20]. Arora et al. [23] have compared different standard test procedures available in India to test the solid biomass cookstoves. They have reported that the PM emission from the same cookstove was 55% lower with bureau of Indian Standards (BIS) test procedures in comparing to the Water Boiling Test (WBT); while CO emission was higher with the BIS test procedure. This suggests the importance of involvement of the same procedure to test the ecological and health benefits of each stove. There is a significant effect of cooking cycle on the emission and efficiency of cookstoves [24]. However, most of the reported tests of the improved cookstoves were conducted under controlled conditions with commercially available condensed solid biomass fuel. The operating conditions of the stove may significantly differ in the rural areas than the controlled environment. Additionally, none of the commercially available cookstoves had been tested with the crop residues or dung cake as fuel [16].

This study intends to compare the performance of three different types of improved cookstoves with three different types of the solid biomass fuels (e.g. fuel wood, dung cake and crop residue) under the normal cooking environment of the rural India. The performance of the improved cookstoves were tested over the traditional cookstove, based on the parameters, (a) consumption of specific fuel; (b) duration of cooking and (c) concentration of pollutants ($PM_{2.5}$ and CO) inside the kitchen during the cooking time using standard methodology. Additionally, this study also tested the thermal efficiency of different types of cookstoves with different solid biomass fuel types.

## 2. Materials and methods

The thermal efficiency and specific fuel consumption in various cookstoves with different types of solid biomass fuel were evaluated following the International standard method of water boiling test (WBT) [25] and controlled cooking test (CCT), respectively [26].

A common standard meal (rice and pulse – *dal*) was selected for this study. Same amount of pulse (skinned green gram: 200 g) and rice (500 g) were taken during each cooking time. The pulse and rice were cleaned with water and 1.5 L of water was kept aside for adding throughout the cooking. The pulse and rice were frequently stirred until they were completely cooked. A flat bottom aluminum pot with lid was used as the cooking vessel.

### *2.1. Study site*

Tests were carried out in a simulated village kitchen (length x width x height: 2.8 m × 2.6 m × 3.3 m) set up in the Jagadeeshpur block (Lat: 26.272726 N, Long: 81.373583 E) of Sultanpur district of the state of Uttar Pradesh, India. There were two open doors and one open window to ensure adequate ventilation in the kitchen. Village women were provided training to use all improved cookstove types and used them regularly for one week prior to the commencement of the experiment. Cooks were performed the cooking without any interference from the research team.

### *2.2. The solid biomass fuel used in the study*

Three different types of locally available solid biomass fuels – fuel wood (FW), dung cake (CDC) and crop residue (CR: mixture of mustard stalks and lentil sticks) – were used during the study. The most commonly available FW in the village was Babul (*Acacia Nilotica*). The dung cakes were locally prepared from cattle dung in round shape by the households and crop residues were collected from local crop fields. The moisture content of each fuel was measured with a portable digital moisture meter, (Delhorst make, USA J-2000 model) during the experiment. The moisture content of the FW was in the range of 9–13% throughout the experiment. All solid fuels were made into nearly same size (length: 10 cm; width: 4 cm; thickness: 4 cm) to maintain nearly similar airspace within