Comparison of a Traditional Cook Stove with Improved Cook Stoves Based on Their Emission Characteristics

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Abstract

A comparative study on the concentration levels of particulate matter (PM) and black carbon (BC) emitted from different types of locally used cook stoves was carried out. Eight different types of cook stoves including six local (a single mouth with chimney (portable), a single mouth without chimney (portable), a double mouth with chimney, a double mouth with chimney (for large scale cooking) and a traditional cook stove and two Indian stoves (Envirofit 3000 single mouth and Prakti with chimney double mouth metallic) were used as sources of emission. The study was carried out at village education research centre, Savar. The concentrations of PM_{10}, $PM_{2.5}$, BC and carbon monoxide (CO) measured at different stages of water boiling test (WBT) from the double mouth with chimney stove (fixed on the floor) were found to be less than any other cook stove. The emissions of PM_{10}, $PM_{2.5}$ and CO from traditional cook stoves found to be higher than those of improved cook stoves whereas BC level should lower value. The PM, BC and CO emissions from Prakti cook stove are lesser than those of Envirofit cook stove but the body of Prakti stove being metallic and became dangerously hot during cooking. Hence, it can be calculated that the locally improved cook stoves are much better than the traditional ones and even than Indian ones available in Bangladesh.

***Keywords*:** Traditional cook stove, improved cook stove

1. Introduction

Indoor air pollution occurring from the combustion of biomass fuel in traditional cook stoves causes a significant public health hazard predominantly affecting poor rural and urban population in many developing countries. A large number of people is exposed daily to harmful emissions and other health risks during biomass burning, typically in low efficient traditional stoves having inadequate ventilation. Majority of those exposed to enhanced level of pollutants are women responsible for food preparation in kitchen, and infant/young children who spend time around the women near the cooking area.

The domestic fuel use has a great impact on health and affect the household economy, women’s time and activities, gender roles and relations, safety and hygiene, as well as global environment. It is estimated that half of the worldwide wood harvest is used as fuel [1]. Further, in some rural settings, poor families expend significant fraction of household income to purchase bio-fuels or devote large fraction of household labour to collect fuels for cooking.

Around 24 million general households in rural area and 5.8 million general households in urban area in Bangladesh use biomass fuels for household cooking purpose [2]. Almost all households use traditional stoves for cooking and other heating purposes. A traditional stove is a mud built cylinder with three raised points on which cooking utensil rests. The stove may be built under or over ground [3]. The common biomasses used for cooking purpose are firewood, leaves, tree twigs, agricultural crop residues such as rice straw, rice husk, jute sticks, sugarcane bagasse, sawdust, cow dung etc. [4]. The consumption of biomass fuels for household cooking with traditional cook stoves in Bangladesh is around 7 to 8 kg per household per day [5-6].

The energy efficiencies of traditional stoves vary between 5-15 % [7]. With a poor thermal efficiency, the traditional cook stove has several disadvantages which are associated with deforestation, troublesome and highbiomass collection time, indoor air pollution and health impact and climate change. In Bangladesh, most of the households cook their foods in traditional cook stoves using biomass fuels because of the unavailability of natural gas. Though a large quantity of carbon dioxide (CO2), a potential greenhouse gas (GHG), is emitted from these stoves, the emission from biomass would be considered as neutral if the biomass fuel cycle would rely on renewable harvesting [8].

Burning biomass in traditional stoves, often with little or no ventilation, emits smoke containing large quantities of harmful particulate matter and other gaseous pollutants. Recent Studies have shown that indoor air pollution levels from combustion of biofuels are extremely high; often many times the standards in different developed countries such as those set by the USEPA for ambient levels [9]. Typically 24-hours mean levels of PM_{10} emitted from the combustion of biofuels for domestic cooking ranges from 300 to 3000 $\mu g/m^3$ depending on the type of fuel, stove and kitchen types [10]. Concentration levels measured depend on where and when monitoring takes place, given that significant temporal and spatial variation (within a house, including room to room), may occur. These small particles are able to penetrate deep into the lungs and appear to have the greatest potential to health hazard [11-12].

There is consistent evidence that exposure to biomass smoke increases the risk of common and serious diseases of both children and adults [5]. From a policy standpoint, although it is health risks that drive policy concern, there is a need for good proxy indicators to guide and facilitate action to mitigate Indoor Air Pollution (lAP). As a result, it is useful to develop ways of reduction of indoor air pollution by improving the traditional cook stoves.

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Determining population exposure will not only improve estimates of the overall impact of indoor air pollution but also help better target policy interventions. The aim of this study is to estimate the emission of PM, BC and CO from improved cook stoves which are locally made and compare these stoves with traditional and as well as Indian cook stoves.

2. Materials and Methods

The village education research center (VERC) facility at Savar was used for the present study. A total of eight cook stoves of which six are locally made and two India-made improved cook stoves were used as the sources of emissions. The local cook stoves include a single mouth with chimney (fixed on the floor), a single mouth with chimney (portable), a single mouth without chimney (portable), a double mouth with chimney, a double mouth with chimney (for large scale cooking) and a traditional cook stove. The double mouth with chimney stove with large scale cooking facility is used for commercial purpose and the rest for family use.

The measurement of particulate matter (PM) and black carbon (BC) was carried out in a kitchen of 11 ft length, 7 ft. width and 8 ft. height with two windows of 3 sq. ft. and a door of 11 sq. ft. Two filter-based Air Matrix Samplers-one for PM_{10} and another for $PM_{2.5}$ and in parallel an Anderson Personal Data logging Real time Air Monitor (PDRAM) sampler were used for measurement in real time (2 min interval) of air particulate emitted during operation of the stove. The BC was measured in the laboratory using reflectance measurement of $PM_{2.5}$ filer sample [13]. An electrochemical sensor based instrument was used for measurement of carbon monoxide (CO) (GasBadge Pro monitor).

For WBT of different cook stoves aluminum made pots was used. Each of the pots was identical with respect to their dead weight, capacity and dimensions. Each pot had a dead weight of 350 gm and a thickness of 1.1 mm with a hemispherical bottom. Each of the pots was 116 mm high and the opening mouth diameter was 245 mm. The highest diameter of the pot was at the middle, which was 290 mm. For single pot, double pot and triple pot cook stoves, WBT required one, two and three pots, respectively, for single test run. For each test run, initially each pot was charged with exactly 4150 ml of water. The cooking fuel used for WBT was locally available wood from mango tree with measured moisture content: 6% (wet basis), gross calorific value (higher heating value) on dry basis 14,400 kj/kg and a calculated net heating value on dry basis 13,080 kj/kg. Higher heating value was determined in the laboratory using bomb calorimeter on wet basis. Net calorific value was calculated using the WBT, version 4.1.2 excels calculation sheet program developed for Shell foundation's-household energy and health programme (HEH) [14]. For multi-pot cook stoves, WBT was terminated with the boiling in the primary pot. No lid was used to cover the pot so that evaporated water freely escapes from the pot. Fuel required heating up the known quantity of water to its local boiling point and the amount of evaporated water up to boiling point was recorded for each test run on all types of cook stoves. From WBT, time to boiling, burning rate, specific fuel consumption, specific energy consumption, firepower, cooking power, turndown ratio, and overall stove thermal 11-26 efficiency were determined. The stoking for entire WBT was carried by a several years experienced woman since stoking rate is highly person dependent. In order to perform this experiment, the wood consists of mango tree was used as fuel. The moisture content and as well as lengths of wood were recorded. The PM_{10} and CO values were recorded for half an hour before the experiment started and as well as after the experiment stopped.

3. Results and Discussion

The emissions from a single mouth cook stove with/without chimney were compared with a traditional cook stove and found that PM_{10}, $PM_{2.5}$ including BC and CO were lower than those of the traditional cook stove (Table 1, 2, 3 and 4). Hence, it may be concluded that the fuel burning in a single mouth cook stove (with or without chimney) either portable or fixed is better than a traditional cook stove.

Table 1. ICS - Single mouth with chimney (on the floor fixed): concrete (local)

Parameter	Unit	Stage of WBT		
		Cold start	Hot start	Simmering
CO	ppm	6.4±0.6	5.8±0.4	4.8±0.5
PM_{10}	μg/m^3	1241±47	1178±13	1031±121
$PM_{2.5}$	μg/m^3	814±25	773±51	680±121
BC in $PM_{2.5}$	μg/m^3	306±18	291±26	256±47

Table 2. ICS - Single mouth with chimney (portable), concrete (local)

Parameter	Unit	Stage of WBT		
		Cold start	Hot start	Simmering
CO	ppm	8.4±0.2	7.3±1.0	6.6±0.8
PM_{10}	μg/m^3	1180±231	966±363	795±296
$PM_{2.5}$	μg/m^3	426±135	355±176	292±150
BC in $PM_{2.5}$	μg/m^3	390±100	322±139	264±114

These types of stoves are locally available and suitable for a single family. On the other hand, the thermal efficiencies of these stoves are higher than that of the traditional stove (Table 5). It was also found that the thermal efficiency (Table 5) and the emission of pollutants (Table 6 and 7) from a double mouth with chimney stove and a double mouth with chimney (for large scale use) were higher than those of a traditional stove.

Table 3. ICS - Single mouth without chimney (portable) concrete (local)

Parameter	Unit	Stage of WBT		
		Cold start	Hot start	Simmering
CO	ppm	11±3.2	9.2±1.2	6.9±1.3
PM_{10}	$\mu g/m^3$	1295±436	1205±415	721±184
$PM_{2.5}$	$\mu g/m^3$	474±221	442±221	263±102
BC in $PM_{2.5}$	$\mu g/m^3$	430±170	400±162	239±75

Table 4. Traditional stove (half underground, fixed: mud (local)

Parameter	Unit	Stage of WBT		
		Cold start	Hot start	Simmering
CO	ppm	13.8±0.6	12.7±0.8	11.9±0.4
PM_{10}	$\mu g/m^3$	1520±27	1146±222	945±20
$PM_{2.5}$	$\mu g/m^3$	998±54	757±190	621±52
BC in $PM_{2.5}$	$\mu g/m^3$	376±27	285±72	234±23

Table 5. Stove thermal efficiency in percentage for different types of stove

No.	Type of stove	Thermal efficiency in %		
		Stage of WBT		
		Cold start	Hot start	Simmering
1	Single Mouth with Chimney (On the Floor Fixed)	17.8	18.6	24.2
2	Single Mouth with Chimney (Portable)	17.8	17.8	22.1
3	Single Mouth without Chimney (Portable)	19.3	22.1	23.0
4	Double Mouth with Chimney (On the Floor Fixed)	24.5	26.1	22.7
5	Double Mouth with Chimney for Large Scale Cooking and Heating Purpose	22.1	25.3	22.3
6	Traditional Stove (Half Underground, Fixed)	**10.4**	**13.4**	**10.4**
7	Envirofit Z 3000 Single Mouth (Fixed)	17.8	18.5	16.4
8	Prakti with Chimney Double Mouth Metallic (Fixed)	20	20.6	19.3

Table 6. Double mouth with chimney (on the floor fixed), concrete (local)

Parameter	Unit	Stage of WBT		
		Cold start	Hot start	Simmering
CO	ppm	5.6±0.4	4.5±0.28	3.2±0.51
PM_{10}	$\mu g/m^3$	1066±8	1000±26	720±49
$PM_{2.5}$	$\mu g/m^3$	700±42	657±35	471±18
BC in $PM_{2.5}$	$\mu g/m^3$	263±21	247±16	177±12

Table 7. Double mouth with chimney for large scale cooking and heating purpose: Concrete

Parameter	Unit	Stage of WBT		
(Local)				
		Cold start	Hot start	Simmering
CO	ppm	6.1±0.75	4.9±0.7	4±0.6
PM_{10}	$\mu g/m^3$	1066±226	958±212	721±257
$PM_{2.5}$	$\mu g/m^3$	798±155	716±139	536±174
BC in $PM_{2.5}$	$\mu g/m^3$	118±29	107±31	83±41

Though the emissions of PM, BC and CO from the Indian cook stoves (Table 8 & 9) compared to those of a traditional cook stove (Table 4) are better from the health point of view and their thermal efficiencies are higher, the Indian stoves are still unsafe as the outer surface of their steel-made bodies becomes dangerously hot while cooking.

Table 8. Envirofit Z 3000 single mouth (fixed): India

Parameter	Unit	Stage of WBT		
		Cold start	Hot start	Simmering
CO	ppm	8.4±0.2	7.3±1.0	6.6±0.8
PM_{10}	$\mu g/m^3$	1180±231	966±363	795±296
$PM_{2.5}$	$\mu g/m^3$	426±135	355±176	292±150
BC in $PM_{2.5}$	$\mu g/m^3$	390±100	322±139	264±114

The results obtained for PM and black carbon emitted from all stoves have been shown in the table-1-9 except table 5 in which the thermal efficiency of the cook stoves are described. During operation of each cook stove the door of the kichen was kept closed so that the concentration of the emitted particles in the room remained adequate to obtain statistically good data. Two mass data for PM_{10} and $PM_{2.5}$ were obtained from the airmatrix instruments for the two month ICS test. The time averaged (PDRAM) data was

Table 9. Prakti with chimney double mouth metallic (fixed): India

Parameter	Unit	Stage of WBT		
		Cold start	Hot start	Simmering
CO	Ppm	5±0.1	4.1±0.1	3.5±0.2
PM_{10}	μg/m^3	939±172	871±160	796±229
$PM_{2.5}$	μg/m^3	702±105	650±97	593±151
BC in $PM_{2.5}$	μg/m^3	105±31	98±31	90±36

normalized to PM_{10} filter data which ensured quality PDRAM data. The PM_{10} data for three phases of test from PDRAM data with normalization.

4. Conclusion

The quantitatively less emission of air pollutants like PM, BC and CO_2 from the combustion of fuels in locally made improved cook stoves compared to those of traditional ones exert less impact on our health while cooking. Besides, the improved cook stoves are also better in consideration of their higher thermal efficiencies than the traditional stoves and even safer than the Indian ones. So the local improved cook stoves are better, available and cheep compared to the traditional and other stoves used in Bangladesh.

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