Performance Evaluation of Biomass Cooking Devices in Household Environment with Various Solid Biomass Fuel

Vivek Kumar Singh*1, R.Sairam2, P L Raviteja2, A Naresh3, R Suresh3

1 Global Institute of land Water & Environment Management, India
2 University of Coimbra-MIT Portugal
3 The Energy & Resources Institute, New Delhi, India

*1vivekkumarsingh22@gmail.com; 2 ram23y@gmail.com; 3 raviteja_fsp@yahoo.com, arthemnaresh@gmail.com
sureshr@teri.res.in

Abstract
This paper is the modest attempt towards experimental study in lab backed with field work for energy efficient cooking devices based on various solid biomass fuel. The study is designed in such a way so as to compare these energy efficient cook stoves as opposed to traditional cook stoves in terms of their thermal efficiency, time of cooking, fuel consumption; finally being helpful in assessing the sustainability of such new technology interventions particularly in rural areas.

Keywords
Biomass, Consumption, Efficiency, Fuel, Technologies

Introduction
Biomass as the fourth largest source of energy worldwide accounts for about 35% of consumption in developing countries and provides a large share of world commercial energy consumption in sustainable energy (Klass, 2004). These biomass sources of energy are considered as the renewable energy. Biomass is used as fuel mainly in developed country in rural area for domestic cooking (Smith et al., 1983). The stoves are classified into three different generations of cookstoves; the first generation (1G) of which refers to three-stone cookstoves approaches with the evolution of humanity. The second generation (2G) replaced the first generation, and are the traditional mud cookstoves. The third and latest generation (3G), also popularly called the improved cookstoves, are differentiated by the technology involved, either combustion or gasification. Objective of performance analysis of cooking device in household environment as forced draft and natural draft cook stove and assessment of clean combustion with biomass fuel with suitable design equipment for biomass heat needs to understand the performance characteristics of biomass in order to avoid possible problems and utilize the biomass effectively. The majority of households in developing countries belong to the category of low income fuel gatherers. Thus, identification of potential users of the technologies is quite crucial in rural area. Many times, the cook stove designs are found to be incompatible with traditional ways of cooking. For example, any change required in the position of the cook while cooking may not be accepted. The paper conclusively proves the role biomass fuel applicability with improved stoves can play towards improving the design and its sustainability. There are important parameters like user acceptance and operational issues which are critical for widespread acceptance of any alternate cooking technologies.

Characteristics of Biomass, Fuels and Their Usage
The chemical composition of biomass varies among species, but basically consists of high, but variable moisture content, a fibrous structure consisting of lignin, carbohydrates or sugars, and ash. Biomass is very heterogeneous in its natural state and possesses a heating value lower than that of coal. Effective use of biomass can be a source of liquid fuel (e.g., biodiesel) or gaseous fuel (e.g., “wood gas”), but the most common use is as a solid fuel (e.g., wood, biomass pellets).

In spite of economic development, traditional solid biofuel (such as wood, agricultural waste, and dried animal manure/ dung cake) is still widely used to meet cooking and space conditioning needs though per capita usage of cooking bio-fuels has declined (Ravindranath 2009). Dependence on unprocessed
solid biofuels is expected to continue in foreseeable future (Ramachandra et al., 2003). The use of firewood or agricultural residues for cooking is accompanied by two environmental problems. First of all, pollutants like suspended particles, carbon monoxide and unburnt hydrocarbons affect the indoor air quality (Jagdish, 2004)

Selection of Fuel

The size and density of the biomass fuel particles are also important as they affect the burning characteristics of the fuel (Hosseini et al., 2010) via the rate of heating and drying during the combustion process. Fuel size also dictates the type of handling equipment, that is, the wrong size fuel will have an impact on the efficiency of the combustion process (Kozinski et al., 1998) and may cause jamming or damage to the handling equipment. Smaller-sized fuel is more common for commercial-scale systems because it is easier to use these smaller sized fuels in feed systems and also allows for finer control of the burn rate by controlling the rate at which fuel is added to the combustion chamber.

<table>
<thead>
<tr>
<th>Biomass fuel</th>
<th>Size for cook stove (cm)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop residue</td>
<td>5<em>3</em>3</td>
<td>15<em>1</em>1</td>
</tr>
<tr>
<td>Bio-dung</td>
<td>2<em>3</em>3</td>
<td>5<em>4</em>2</td>
</tr>
<tr>
<td>Firewood</td>
<td>4<em>3</em>3</td>
<td>30<em>4</em>3</td>
</tr>
</tbody>
</table>

Selection of Device

Selection of stoves to assess the performance has been made based on the following criteria: Metallic single pot model, Certified manufacturer approved model by Ministry of New and Renewable Energy (MNRE) 2009 and Certified/Claimed by manufacturer regarding model (a)Thermal efficiency: more than 20 percent. (b) Life Span: more than 2 years. (c) Emission is less than that of a conventional or Traditional cook stove.

Natural Draft Vs Forced Draft Cook Stove.

In a traditional mud stove, combustion happens almost as soon as volatilization around the solid fuel zone; which can lead to significant emissions of products of incomplete combustion. In contrast, force draft (FD) stoves and natural draft (ND) stoves tested were designed on the basis of principles of micro-gasification to improve combustion efficiency (Anderson et al., 2007). In micro-gasification stoves, air supply [from either fans (FD) or free convection (ND)] is partially supplied into the combustion chamber from primary small openings located at the bottom of the stove (Mukunda et al., 2011). The remaining air supply is channelled to the top of the combustion chamber (and preheated) through secondary small openings. Forced draft stove reduces smoke by up to 80-90%, significantly optimising fuel consumption, and it can make cook faster and is portable, runs on battery power pack.

Methodology

Biomass fuel applicability performance test is based on two international standard protocols, namely, Water Boiling Test (WBT) and Controlled Cooking Test (CCT). Both these tests are conducted separately to find specific output as Thermal efficiency and Specific fuel consumption respectively. These test protocols should be tested in laboratory situation. The difference between the laboratory situation and a practical situation has often been posed in such a manner as to suggest that the laboratory work cannot provide any guidelines for the development of efficient stoves. It is claimed that only field work can lead to practical designs. Hence modified test for WBT and CCT were conducted in field of rural environment to compare various fuels and devices. The laboratory tests (WBT and CCT) were carried out in a simulated kitchen testing facility at local laboratory condition set up in Kaima village in the Jagdishpur block of Sultanpur district in Uttar Pradesh, India.

Discussion and Implication

Thermal Efficiency

Thermal efficiency is a ratio of the work done by heating and evaporating water to the energy consumed by burning wood. As WBT consists of cold start, hot start and simmer phase, thermal efficiency of various models of cook stoves represented in graph-1, Thermal efficiency for forced draft biomass cook stove is in the rage 30-37% including cold start, hot start and simmer phase. Natural draft biomass cook stove and traditional cook thermal efficiency are in the range 20-28% and 12-19% respectively.

When the stoves were lit with hard wood, forced draft stove showed maximum thermal efficiency followed by ND and TC Stoves. Similarly, at high power phase (hot start), when lit with crop residue, the maximum efficiency was shown by FD stove followed by ND and TC stoves. The applicability of crop residue in
simmering phase was found to be slightly difficult as the crop residue burns well and catches fire fastly. Bio-
dung was found to be applicable in all the three stoves when break the dung cake into small pieces. In general, it was found that FD stove was giving maximum thermal efficiency irrespective of the fuel and test phases, followed by ND and TC stoves.

**Fire Power**

Fire power is defined as the ratio of the wood energy consumed by the stove per unit time, and indicates the average power output of the stove during the high-power phase. Fire-power of FD, ND and TC is represented in figure -2. From the figure it is clear that for all fuel types, TC stove shows high fire power followed by ND and FD cookstoves. It should be noted that higher power fire will lead to maximum heat loss and unstable flame during the burning of biomass fuel with cooking device which in turns leads to low efficiency of the device. If fire power is low compared to fuel consumption and time for same tasks with different devices, the device will show high efficiency.

**Total Cooking Time**

This is also an important indicator of stove performance in the CCT. Depending on local conditions and individual preferences, stove users may value this indicator more or less than the fuel consumption indicator. This is calculated as a simple clock difference. The time of cooking was found to be low when cooked with FD stove while the maximum cooking time is observed for TC stove for cooking the same quantity of food. The estimates of cooking time are depicted in the graph-3.

**Specific Fuel Consumption**

This is one of the principal indicators of stove performance for the CCT, which indicates quantity of fuel consumed to cook a given amount of food under “standard cooking task”. The Specific fuel consumption (SFC) per meal is expressed in grams of fuel used per kilogram of cooked food. The comparisons made in graph - 4 must be done within each FD, ND and TC Stove.

**Conclusions**

The experiment results indicate that modern solid
biomass cook stoves in real kitchens at field level have impressive performances with firewood, bio-dung as well as crop–residues and result of thermal efficiency and fire power, specific fuel consumption and time of cooking indicating applicability of various biomass fuel with improved cook stove. Operation of improved cook stove with bio-dung encounters slightly difficulty and need to break up in small pieces. To make it functioning fuel loading requires continuing. Thus there is a need to continue research and development in designs and applicability to mixed solid biomass fuel with different stove types. Individual factors interact to influence adoption of cooking technologies at household level.

ACKNOWLEDGMENT

The author sincerely thanks the Energy Resources Institute, New Delhi; as well as the field staff of TERI PMU Jagdishpur Utter Pradesh India for their enthusiastic cooperation in field level data collection.

REFERENCES


Vivek Kumar Singh completed his M.Tech (Energy & Environment Engineering) in 2008 from Vellore Institute of Technology Vellore, Tamilnadu. He is a Consultant at Global Institute of land Water & Environment Management Delhi. He has published many papers in international journals/conferences. His research interests include the biomass, solar and renewable energy systems.

R.Suresh is Research Associate at The Energy & Resources Institute, New Delhi. He has published many papers in national/international journals/conferences. His research interest is indoor air pollution and has more than ten years of experience in this field.

R.Sairam a IGBC AP completed his B.Tech (Facilities & Services Planning) from JNA&FA University. He is currently pursuing MS (Energy for Sustainability) from University of Coimbra-MIT Portugal.

P.L. Raviteja completed his B.Tech (Facilities & Services Planning) from JNA&FA University. He is currently pursuing MS (Energy for Sustainability) from University of Coimbra-MIT Portugal.

A Naresh completed his B.Tech (Facilities & Services Planning) from JNA&FA University. He is currently pursuing MS (Energy for Sustainability) from University of Coimbra-MIT Portugal.