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# Influence of testing parameters on biomass stove performance and development of an improved testing protocol

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ABSTRACT

Biomass fuels are used by nearly half the world's population on a daily basis for cooking. While these stoves often look simple in appearance they are notoriously difficult to test. By their very nature biomass stoves are typically fairly uncontrolled devices which often exhibit a large amount of variability in their performance. In order to characterize a stove and understand the processes which are occurring inside, and through this begin to design better stoves, this variability and uncertainty needs to be reduced as much as possible. A parametric study was conducted to better understand what factors lead to variability and uncertainty in cookstove test results and should be controlled in order to obtain repeatable results. Using the Water Boiling Test as a starting point, it was found that significant reductions in test variability could be achieved through minimizing the amount of water vaporization which occurs during the test. Uncertainty was further reduced by using fuels with consistent moisture contents. Based on these findings a new testing methodology, the Emissions and Performance Test Protocol, has been proposed and the benefits of moving to this method presented.


## Introduction

Tables 2, 3, 5, 6, Fig. 9

Half of the world's population cooks domestically with simple biomass stoves (Bruce et al., 2000). This widespread practice generates massive amounts of indoor air pollution (IAP) which has been linked to 2.6% of global illness (Rumchev et al., 2007). From an environmental perspective, unsustainable biomass use has resulted in deforestation and significant levels of greenhouse gas production (including black carbon emissions) (Smith et al., 2010). Although improved cookstoves have been developed which significantly reduce emissions of toxic gases and increase thermal efficiency, the inherent stochastic nature of biomass combustion, combined with natural variations in use, make quantifying stove performance challenging. There are limited protocols (Bailis et al., 2007b; Bureau of Indian Standards, 1991; Xiangjun, 1993) and no formal standards have been developed specifically for domestic biomass cookstoves. While there are many factors necessary to successfully design and disseminate a clean burning cookstove, one is a testing protocol which results in consistent, reliable, and repeatable results. While testing protocols alone will not result in large scale adoption of improved cookstoves, they will ensure that clean, fuel efficient, highly reliable products with a high chance of success will be available for dissemination. The methods of evaluating stove performance currently being used fail to yield consistent results or rely on unreasonable correction factors. This has resulted in a lack of high quality, comparative data that is needed to support stove design efforts. The aim of this study is to determine the effects of controllable test parameters on the results of biomass cookstove testing to help inform the development of a highly repeatable test protocol.

One of the most common protocols currently in use to evaluate stove performance is the Water Boiling Test (WBT) used to measure the thermal efficiency of a cookstove. However, the WBT is increasingly used to measure not only the efficiency, but also the emissions of cookstovess. The WBT is explored parametrically using both experimental and analytical methods to understand sources of variation and uncertainty which arise in the protocol. The Emissions and Performance Test Protocol, a modification which addresses these sources of uncertainty, is proposed and evaluated as an improved method.

## Background

The gaseous and particulate emissions released from biomass combustion are known to be damaging to both the environment and human health. Biomass combustion in traditional stoves drastically reduces indoor air quality and contributes to 2 million deaths annually from acute lower respiratory disease (Bruce et al., 2000). The World Health Organization (WHO) has linked smoke inhalation from biomass combustion with a doubling in the occurrence of respiratory disease in children (Khalequzzaman et al., 2007; WHO/UNDP, 2004). The implications of biomass cookstove use are not limited to local impacts and human health factors. Wood cookstove use can

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**Table 1**
Experimental matrix and number of test replicates conducted.

| Test parameter | Test version | Replicates |
|---|---|---|
| Fuel geometry | Small | 3 |
| | Medium | 3 |
| | Large | 3 |
| Fuel moisture content | 4% | 2 |
| | 7% | 3 |
| | 13% | 2 |
| | 30% | 2 |
| Pot geometry | 1 | 3 |
| | 2 | 3 |
| | 3 | 3 |
| | 4 | 3 |
| | 5 | 3 |
| | 6 | 3 |
| Pot insulation | No insulation | 3 |
| | Insulation | 3 |
| Total | | 42 |

increase deforestation and may account for 1–2% of annual global warming (Ahuja, 1990) if not done sustainably. In addition, the particulate matter released during biomass combustion can be carried hundreds of miles from its source (Naeher et al., 2007) having global environmental impacts (U.S. Environmental Protection Agency, 2008).

Test standards will be required in order to achieve the significant improvements in biomass cookstove emissions needed to have an impact on human health and the global environment. To reach the billions of people in need of clean stoves, the validity of the standards will need to be recognized by governments on an international level and will need to meet the requirements of industry. While there is a time and place for small scale stove dissemination, it will likely take mass production and the active involvement of business and industry specialists, to produce the millions of stoves which are required. For government, business, and industry to participate in stove dissemination, a reasonable, realistic, and repeatable testing protocol will be required.

### *Volunteers in Technical Assistance*

Some of the first serious efforts to develop test protocols specifically for biomass cookstoves was facilitated by Volunteers in Technical Assistance (VITA) in 1982. The VITA tests were an attempt to improve the comparability of stove designs, help groups testing stoves to get the most from their results, to aid in reliable interpretation of results. A key outcome of the VITA sponsored event was the formalization of three protocols for assessing fuel efficiency for cookstoves; the Water Boiling Test (WBT), the Kitchen Performance Test (KPT) and the Controlled Cooking Test (CCT). The WBT was designed to be a simple laboratory test to be used to compare fuel consumption between stove designs and acknowledged that it may not directly correlate to stove efficiency during actual cooking. The KPT was designed as a field evaluation of stove fuel efficiency in homes during actual cooking practices. While both the WBT and KPT can provide useful information they in some ways represent the extremes of cookstove protocols. The WBT and lab test with only limited similarities to actual use and the KPT a fairly uncontrolled test but extremely representative of what the end user will see. The CCT was developed to be an intermediary test, a test where stoves are used to cook real meals but under more repeatable conditions (Bussman et al., 1985).

**Table 2**
Statistical significance of wood geometry on stove performance using an unpaired Student *t*-test analysis, differences considered statistically significant at $p \leq 0.05$.

| | Small | Medium |
|---|---|---|
| *Wood use* | | |
| Medium | 0.51 | |
| Large | 0.92 | 0.56 |
| *CO* | | |
| Medium | 0.87 | |
| Large | 0.69 | 0.54 |
| *PM* | | |
| Medium | 0.08 | |
| Large | 0.22 | 0.87 |

**Table 3**
Statistical significance of moisture content on stove performance using an unpaired Student *t*-test analysis, differences considered statistically significant at $p \leq 0.05$.

| | 4% | 7% | 13% |
|---|---|---|---|
| *Wood use* | | | |
| 7% | 0.16 | | |
| 13% | 0.90 | 0.14 | |
| 30% | 0.47 | 0.10 | 0.46 |
| *CO* | | | |
| 7% | 0.78 | | |
| 13% | 0.01 | 0.15 | |
| 30% | 0.43 | 0.94 | 0.04 |
| *PM* | | | |
| 7% | 0.16 | | |
| 13% | 0.25 | 0.54 | |
| 30% | 0.25 | 0.93 | 0.60 |

### *Revised testing protocols — Household Energy and Health Programme*

Revised versions of the WBT, KTP, and CCT protocols were prepared for the Household Energy and Health Programme in 2004 and 2007 with support from the Shell Foundation. The latest WBT version can be found online (The Partnership for Clean Indoor Air, 2010; University of California, Berkeley, 2011). While the tests are similar to those developed in collaboration with VITA in the early to mid 1980s minor modifications have been made to reduce variability and increase the usability of the protocols.

It can be argued that revised WBT and the work of the Household Energy and Health Programme are some of the most important stove development work which has occurred in the past 30 years. A special issue of Energy for Sustainable Development released in 2007 provides an excellent overview of recent stoves research and projects which have resulted from the Household Energy and Health Project, many of them utilizing the revised WBT protocol (Smith, 2007).

### *Carbon credits and the Gold Standard*

The concept of using carbon credits or carbon financing as part of an improved stove program is gaining ever increasing attention. One methodology being utilized to assess impact is based on the Kitchen

**Table 4**
Material and dimensions of cook pots tested.

| Pot | Material | Width (cm) | Height (cm) | Mass (kg) |
|---|---|---|---|---|
| 1 | Stainless steel | 25.5 | 25.5 | 0.75 |
| 2 | Stainless steel | 25.5 | 16.5 | 0.83 |
| 3 | Stainless steel | 23 | 20 | 0.65 |
| 4 | Aluminum | 25.5 | 18 | 0.32 |
| 5 | Porecelain coated mild steel | 24 | 18.5 | 0.58 |
| 6 | Porecelain coated mild steel | 35.5 | 25.5 | 1.19 |