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DEVELOPMENT OF A ROCKET COOKSTOVE WITH A FRUSTUM CHAMBER AND HEAT EXCHANGER

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ABSTRACT

The main goal of this study is to develop an improved cooking stove that reduces the pressurplaced on local forests by reducing the amount of wood the stoves consume.

A rocket cookstove with a frustum chamber and a heat exchanger was designed, fabricated and evaluated. It is made of 0.8mm G.I. sheet and weighs about 2.9 kg. The rocket cookstove have four separable parts (1) the firewood shelf, (2) frustum chamber, (3) body, and (4) heat exchanger. The performance of the cookstoves was determined by a Water Boiling Test (WBT). A rocket cookstove with a frustum chamber and a heat exchanger performs best among the three cookstoves. The time required to boil 5 liters of water from a cold-start and a hot-start high-power tests by a rocket stove with the heat exchanger were about 24 and 19 minutes, respectively. These were significantly shorter at 5% level of significance compared to the rocket stove without heat exchanger exhibiting about 28 and 25 minutes, respectively; and to the traditional open-air stove requiring about 36 and 29 minutes, correspondingly.

As a result, the specific consumption of the rocket cookstove with a frustum chamber and a heat exchanger was significantly lower by about 50% during the cold-start high-power test and about 60% during the hot-start high-power test.

The design of this improved rocket cookstove with a frustum chamber and a heat exchanger reveals a significant advantage over the traditional open-air stove. Hence, using this type of stove, the wood consumption for cooking and heating can be reduced by as much as 50% as consumed by the traditional open-air stove.

Furthermore, this can alleviate the pressure on local forests and can reduced risk on health of man and the environment.

INTRODUCTION

Philippines is considered as one of the developing countries in Asia and in the World. In developing countries, cookstoves are the most common way of cooking and heating food, however, developing countries consume little energy compared to developed nations; in spite of this, over 50% of the energy that they do use goes into cooking food (Wikipedia, 2007). Hundreds of millions of people, many of them in developing countries, are completely reliant upon wood for fuel – a fact that is not likely to change in the next several decades (Matthews, 2006).

Household cooking is one of the most important energy issues today and has a major impact on human health and the landscape ecology of developing nations (REAP-Canada, 2004).

Appropriate technology (AT) is technology that is designed with special consideration to the environmental, cultural, social and economic aspects of the community it is intended for; with these goals in mind, AT typically requires fewer resources, is easier to maintain, has a lower overall cost and less of an impact on the environment (Wikipedia, 2007).

One of the greatest needs of all people affected by crisis is firewood to heat their homes, cook their food, and treat water for drinking and food preparation.

However, deforestation and erosion are often the end result of harvesting wood for cooking fuel. The main goal of most improved cooking stoves is to reduce the pressure placed on local forests by reducing the amount of wood the stoves consume (Wikipedia, 2007).

Cooking with wood or charcoal stoves is also bad for the health. When burned, wood and charcoal don't combust, or get burnt, completely and, as a result, gases (like carbon monoxide, nitrogen oxide, sulfur oxide, and organic compounds) are given off are toxic to people and bad for the environment (HORIZON Solutions, 2007). Household use of solid fuels is thus estimated to be the largest single environmental risk factor and ranks sixth among all risk factors examined for ill-health (Figure 1; Smith, et. al. 2005).

MATERIALS AND METHODS

Design and Fabrication of the Stove

A rocket cookstove with a frustum chamber and heat exchanger was fabricated based on the following criteria: (1) ease of fabrication, (2) strength and durability, (3) portability, (4) high temperature inside the burning chamber, and (5) cost-efficient.

The cookstove (Figure 2a) had four separable parts (1) the firewood shelf, (2) the burning chamber, (3) the body, and (4) the heat exchanger. All these four parts were made of 0.8mm G.I. Sheet.

Figure 1

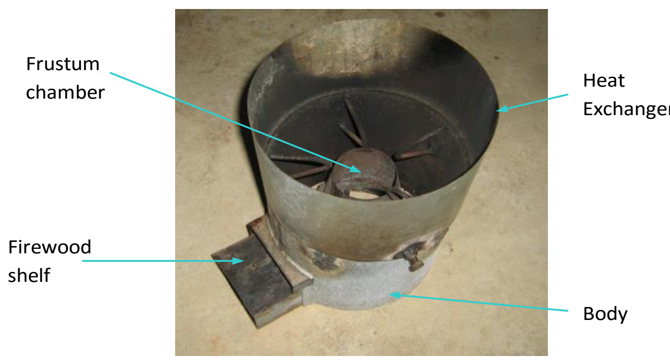

Figure 1

Materials, Tools and Equipment

To achieve the objectives of the study, the following materials, tools and equipment were acquired for the fabrication of the cookstove as shown in Figure 1.

1 . sheet of 0.8 mm x 4 ft x 8 ft plain G.I. Sheet
2 . length of 6 mm deformed bar
3 . 1/4 kilo welding rod
4 . 1 piece of metal sheet scissors
5 . 3 laboratory thermometers
6 . hammer
7 . pull-push rule
8 . welding machine
9 . oxy-acetylene welding equipment
10 . portable electric drill
11 . weighing scale

Stove Evaluation

Prior to the gathering of the data, a pre-study will be done to initially assess the operation of the stove. The rocket cookstove with frustum chamber and heat exchanger was evaluated against its own but without the heat exchanger and against the traditional open-air tripod stove based on the following parameter:

a. Time to boil water,
b. Wood burned or consumed,
c. Specific consumption, and
d. Burning rate.

In order to assess the performance of the stove, the modified 2003 version of the well-known Water Boiling Test (WBT) by Rob Bailis and others of the University of California, Berkeley School of Public Health was used. The excerpts of the said WBT as applied in the data gathering were the following:

Phase 1: High Power (Cold Start)

1. A timer was prepared, but was not started until fire has started.

2. A standard pot was filled with 5 kg (5 liters) of clean room temperature water. The amount of water was determined by placing the pot on the scale and adding water until the total weight of pot and water together is 5 kg more than the weight of the pot alone. The weight of pot and water were recorded in the data and calculations sheet. The same amount of water was used for each test iteration.

3. Using the wooden fixtures, a thermometer was placed in each pot so that water temperature may be measured in the center, 5 cm from the bottom. The initial water temperature was recorded and confirmed that it does not vary substantially from the ambient temperature.

4. A 50x50 cm thin G.I. sheet pan was used as bottom base of the stove to accurately weigh charcoal. The weight of this pan together with the firewood shelf and frustum chamber of the stove was determined.
5. The stove was at room temperature. The fire was started in a reproducible manner according to local practices. A kerosene was used as a starting material to put the stove on fire.

6. Once the fire had caught, the starting time was recorded. Throughout the following "high power" phase of the test, the fire was controlled to bring the pot rapidly to a boil without being excessively wasteful of fuel.

7. When the water in the first pot reached the pre-determined local boiling temperature as shown by the thermometer, the following rapidly done:

    a. The time was recorded at which the water in the pot first reached the local boiling temperature. This temperature was recorded also.

    b. All wood were removed from the stove and the flames were extinguished by blowing on the ends of the sticks. All loose charcoal was knocked from the ends of the wood into the firewood shelf for weighing charcoal.

    c. The unburned wood removed from the stove was weighed together with the remaining wood from the pre-weighed bundle. Results were on the data and calculation form.

    d. For ease and fast weighing of charcoal, the charcoal pan together with firewood shelf and frustum chamber with the charcoal in it was weighed. This weight was recorded on the weight of charcoal + container of the data and calculation Form.

This completes the high power phase. The high-power hot-start test was started immediately while the stove was still hot.

Phase 2: High Power (Hot Start)

1. The timer was reset, but was not started until fire has started.

2. The pot was refilled with 5 kg of fresh cold water. The pot (with water) was weighed and the initial water temperature was measured; both measurements were recorded on the data and calculations sheet.

3. The firewood was lighted using kerosene.

4. The starting time was recorded and the pot was brought rapidly to a boil without being excessively wasteful of fuel using wood from the second pre-weighed bundle.

5. The time was recorded at which the pot reached the local boiling point as indicated on the data and calculation form. Temperature was recorded for the first pot.

6. After the boiling temperature was reached, the following were quickly done (speed was important at this stage because we want to keep the water temperature as close as possible to boiling in order to allow us to proceed directly to the simmer test):

   a. The unburned wood was removed from the stove. Any loose charcoal was knocked off inside the frustum chamber (the charcoal was not weighed at this stage).

   b. The wood removed from the stove was weighed together with the unused wood from the previously weighed supply. Result was recorded on Data and Calculation form.

7. The wood removed from the fire was replaced and relighted and proceeded immediately with the low power test.

Phase 3: Low Power (Simmering)

1. The timer was reset.

2. The thermometer was replaced in the pot. The fire was adjusted to keep the water as close to 3 degrees below the established boiling point as possible.

3. The fire was maintained for 45 minutes at a level that keeps the water temperature as close as possible to 3 degrees below the boiling point.

4. After 45 minutes the following were rapidly done:

   a. The finish time of the test was recorded on the Data and Calculation Form under the heading “Finish: 45 minutes after Pot # 1 boils”.

   b. All wood from the stove were removed and any loose charcoal was knocked inside the frustum chamber. The remaining wood was weighed including the unused wood from the pre-weighed bundle.

   c. The final water temperature was recorded on data and calculation Form (it should still be roughly 3 °C below the established boiling point).

   d. The pot with the remaining water was weighed. The weight was recorded on the data and calculation Form.

   e. For ease and fast weighing of charcoal, the charcoal pan together with firewood shelf and frustum chamber with the charcoal in it was weighed. This weight was recorded on the weight of charcoal + container of the Data and Calculation Form.

This completes the WBT. The test was conducted a total of three times for each stove.

$$BR = \frac{wood\_consumed}{time\_required\_to\_finish\_a\_test}$$

Data Analysis

To compare means simultaneously, a one-way factor analysis of variance at 5% level of significance were done separately on the three different phases of the water boiling test. LSD was employed on the post hoc tests.

RESULTS AND DISCUSSION

Water Boiling Test (WBT) at High-Power Cold-Start

A high-power cold-start is a first phase of the three-phase water boiling test of stoves. It is done with a stove where it is cold at room temperature and uses a pre-weighed bundle of wood to boil a measured quantity of water (5 kgs or 5 liters) in a standard pot. The pot was brought to a boil as rapidly as possible without being excessively wasteful of heat.

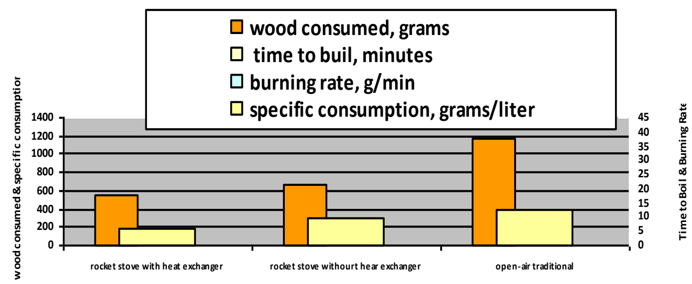

Figure 2. Results of High-Power Cold-Start on WBT

Figure 2 represents the performance of the three different single-pot cookstoves. In these parameters, a stove with a lesser values performed better. From the data as illustrated in a graph, a rocket cookstove with a heat exchanger performs best among the three, while open-air traditional stove performs the least. The time required to boil 5 liters of water from a cold-start by a rocket stove with a heat exchanger was about 24 minutes which was significantly shorter at 5% level of significance compared to the rocket stove without the heat exchanger and the open-air traditional stove that require about 29 and 35 minutes, respectively. In this design, the heat exchanger was an additional yet removable part of the rocket stove. With the heat exchanger of the rocket stove, the specific consumption was about 121 g/liter that was significantly lower at 5% level compared to the rocket stove without the heat exchanger and the open-air traditional stove having 137 g/liter and 247 g/liter, respectively. As figure 2 shows, the specific consumption by the rocket cookstove with a frustum chamber and heat exchanger was significantly lower by around 50% compared to the traditional open-air stove. Nevertheless, the performance of the rocket stove without the heat exchanger was still significantly better at 5% level compared to the open-air traditional stove. At this phase, burning rates of wood were not significantly different a 5% level.

Water Boiling Test (WBT) at High-Power Hot-Start

This test follows immediately after the first phase while the stove is still hot. Again, it uses a pre-weighed bundle of wood to boil a measured quantity of fresh cold water (5kgs or 5 liters) in a standard pot. In the same manner, the pot was brought to a boil as rapidly as possible without being excessively wasteful of heat.

Figure 3. shows the performance of the cookstoves from a hot-start high-power test. Similarly, a stove with a

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lesser values performed better. In this phase the time required to boil the same amount of fresh cold water, wood consumed and specific consumption were basically reduced. Related to a high-power cold-start, a rocket cookstove with a heat exchanger performs best among the three, while open-air traditional stove performs the least. The time required to boil 5 liters of water from a hot-start by a rocket stove with a heat exchanger was reduced to 19 minutes which was significantly shorter at 5% level of significance compared to the rocket stove without the heat exchanger and the traditional open-air stove that require about 25 and 29 minutes, respectively. Consequently, the specific consumption was significantly different with each other at 5% level. Likewise, the specific consumption from a hot-start high-power test by the rocket cookstove with a frustum chamber and heat exchanger was significantly lower at 5% level of significance by around 50% and 10% more compared to the traditional open-air stove.

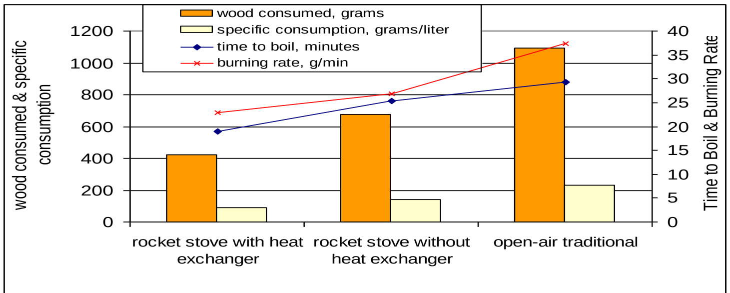

Figure 4.2 Results of High-Power Hot-Start on WBT

Low Power (Simmering)

This was the third and the last phase of the WBT that follows immediately after the second phase. At this period, the amount of fuel (firewood) required to simmer a measured amount of water at just 3 ^{0}C below boiling for 45 minutes were determined.

The amount of wood consumed and the specific consumption of the rocket stove with exchanger were still the least compared to the other two stoves. The traditional open-air stove was still having the highest values in fuel consumption. However, statistical analysis revealed a non-significant difference among the different cookstoves in terms of wood consumed, specific consumption and burning rate.

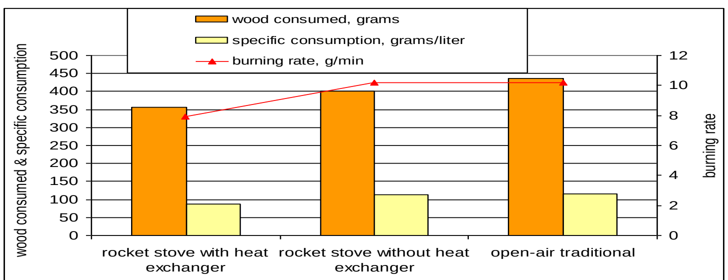

Figure 4.3 Results of Low-Power (Simmering) of WBT

CONCLUSION AND RECOMMENDATION

The design of this improved rocket cookstove with a frustum chamber and a heat exchanger reveals a significant advantage over the traditional open-air stove. Hence, using this type of stove, the wood consumption for cooking and heating can be reduced by as much as 50% as consumed by the traditional open-air stove. Furthermore, this can alleviate the pressure on local forests and can reduced risk on health of man and the environment.

RECOMMENDATIONS

The performance of the stove by water boiling test was a rough approximation of actual cooking as it is done in a controlled condition. Therefore, it can't provide much information about how the stove performs when cooking real foods (Bailis, et. al, 2007). Thus, the following recommendations are necessary:

1. conduct a Controlled Cooking Test (CCT) and Kitchen Performance Test (KPT);

2. fabricate the stove using a stainless sheet and perform the same test;

3. make a design combination that can use biomass other than wood;

4. conduct an economic analysis on the use of the stove.

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