EVALUATION OF A WOOD FIRING STOVE PERFORMANCE USING THE WATER-BOILING TEST

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Abstract*. The most frequently used fuel wood technology is the open fire. People who use such technology is exposed to emissions originated that has as consequence serious adverse health effects, affecting mainly women and young children. A damage associated with smoke from open fire is the acute respiratory infections, which cause, annually, near 1.2 million premature deaths among children less than 5 years of age. For several decades, stove improvements have been promoted to reduce fuel-wood consumption and to improve farmer´s quality of life. Since health and fuel-saving benefits of improved wood-burning stoves are related with its increased efficiency, evaluation of energy performance is critical to develop more effective technologies. Measurement of energy efficiency for a wood-burning stove is difficult as the tests should reflect the conditions under which the stove will be used in real kitchen. While a standardized global test may seem at first desirable to compare across designs, in practice, since cooking and stove usage are quite different between different regions, and even more so at national and global levels, this has proved to be quite challenging. This paper presents an evaluation of a wood firing stove manufactures by a Brazilian company named Ecofogão located in Belo Horizonte, MG. Such evaluation was performed using a protocol named water-boiling test (WBT) which allows the quantification of its thermal efficiency. The tests were done at the Federal University of Para-Brazil with Amazonian wood as fuel. Its efficiency according the WBT was about 29%.*

Keywords*: wood firing stove, biomass, water-boiling test*

1. INTRODUCTION

Biomass represents between 50% and 90% of primary energy consumption in developing countries, and from 12% to 15% of global primary energy consumption (Wereko-Brobby, 1996). In developing countries, where 77% of the world's population lives mainly in rural areas and in poor urban zones, such biomass is used for cooking, for water heating, for heating and for thermal power generation in a large variety of small industries. The most frequently way to convert biomass in heat is the open fire. Unfortunately, people that use this technology are exposed to emissions originated from inefficient combustion which are associated with serious adverse health effects, affecting mainly women and young children. Damage associated with smoke from open combustion is the acute respiratory infections, which cause nearly 1.2 million premature deaths per year among children less than 5 years of age (Smith and Mehta, 2003 and Smith, 2003).

For several decades, improvements on stoves have been promoted to reduce fuel-wood consumption and to improve quality of life for rural population. Since health and fuel-saving benefits of improved wood-burning stoves are related with its increased efficiency, evaluation of the stove energy performance is critical on the developing a more effective technology. Measurement of stove energy performance is difficult because the tests should reflect the real conditions of the stove uses. While a standardized global protocol may seem at first desirable to compare across designs, in practice, since cooking and stove usage are quite different between different regions, and even more so at national and global levels, this has proved to be quite challenging (Smith, 1992 and Manibog 1984).

Among several proposed protocols to quantify stove wood-burning efficiency, the water-boiling test (WBT) is very attractive due to the fact that it is simple and fast. On the other hand, it does not simulate the real stove operation. WBT consists of leaving a top-open-aluminum tray filled with water on the stove hot plate and measure the mass flow rate of water evaporation from the tray and the liquid water temperature. If the biomass consumption rate is known, stove energy efficiency is obtained by the ratio between the energy transferred to the water (liquid and steam) and the biomass chemical energy (knowledge of the biomass LHV is required) (Shell 2003).

A Brazilian wood-stove manufactured by Ecofogão Ltda (Ecofogão, 2006) located at Belo Horizonte – Brazil was tested at EBMA/UFPA laboratory. The model tested was the Metal Multiple Use mainly composed by a solid cast-iron plate of 56x56 cm and a galvanized steel cabinet and fabricated in industrial scale Figure 1. Its combustion chamber design was based upon the "rocket stove combustion chamber model" where biomass is burned and the exhaustion hot gases transfer heat to the cast-iron stove top. The use of rocket stove combustion chamber allows the exhaustion gases to achieve high temperatures making the combustion more efficient with low emission of particulate matter. This text presents evaluation of such wood-stove through the determination of its thermal efficiency, using the Boiling-Water Test, the cast-iron plate temperature mapping and the gas emissions composition.

Figure 1: Metal multi-use wood stove manufactured by Ecofogão and tested at EBMA/UFPA (EBMA 2007).

2. MATERIALS, METHODS AND EQUIPAMENTS UTILIZED

The water-boiling test protocol was revised by Rob Bailis, Damon Ogle Nordica MacCarty and Dean Still from what was firstly developed by Kirk R. Smith e Rufus Edwars to be used by Shell Foundation (Shell, 2008). This protocol was chosen because it is simple to be performed, gives satisfactory result and is largely used around the word. This test objectives the quantification of the stove efficiency measuring the wood-stove capability to transfer heat from biomass combustion to the water within the aluminium trays during a 45 minutes test. The Equation (1) was applied to compute the wood-stove efficiency and the meaning for its parameters are described in the Table 1

$$\eta = \frac{\left(A/a\right) M_{H_2O} . C(T_e - T_i) + M_{evap} . L}{M_{comb} . LHV^t} . 100 \qquad (1)$$

Table 1: Definitions and unities of parameters at Equation (1)

		Units
η	Stove efficiency	%
M_{H2O}	Initial mass of within all trays	kg
C	Water specific heat	kJ/kg-°C
T_e	Boiling temperature at local pressure	°C
T_i	Initial water temperature	°C
M_{evap}	Mass of the evaporated water	kg
L	Vaporization latent heat for water at local pressure.	kJ/kg
M_{comb}	Consumed mass of biomass	kg
LHV^t	Biomass low heating value	kJ/kg
A/a	Area correction factor: ratio between the cast-iron-plate area with summation of all bottom areas from aluminum trays.	

Figure 3 shows a scheme for the apparatus organization. Two thermocouples (TC) were applied and their specification is presented in Table 2. The first TC was permanently located at point 5 and was used to measure the exhaustion gases temperature. The second TC was mobile and moved among the four aluminium trays measuring water temperature.

Materials and equipments utilized: the equipments utilized are listed in the **Table 2**

Table 2: Materials and equipments utilized

Function	**Materials or Equipments**	**Specifications**
Fuel	Biomass - Jatobá (*Hymenaea Courbaril)*	Blocks with dimensions of 20mmx10mmx600mm. Moisture content varies between 9 a 12 %*)*
Water temperature measurements	Thermocouple	K type
Gas temperature measurements	Thermocouple	K type
Water recipient	Aluminium tray	4 aluminium trays filled with water
Water mass measurements	Digital scale	
Fluid to be evaporated	Water	

The procedure adopted to run experiments began with the energetic characterization for the fuel biomass through its proximate analysis and high heat value. The ultimate analysis for the fuel biomass is not available therefore the LHV calculation was performed considering (EBMA, 2006). The fuel biomass was weight and part of them introduced in the combustion chamber and ignited with help of alcohol. The exhaustion gas temperature, TC5, was monitored up to achieve its maximum, and then small amounts of biomass were fed the combustion chamber until all weighted biomass were at fire. After the TC5 achieved its highest temperature, TC mobile was used to measure the water temperature inside all four trays. After all weighted biomass was consumed, the mass balance was applied for the biomass and water involved in the process, the ashes were cooled manually and weighted, as well as the remaining water.

To guarantee the experiment's repeatability and reliability, an apparatus was developed to support the thermocouples and keep them immerse in the tray with water, keeping the same deepness and not touching the bottom of the tray. The apparatus is shown in the **Figure 2**. Aluminium trays always stayed on the same position during repeatability runs following the arranging shown in the **Figure 3**.

Figure 2: Experimental apparatus.

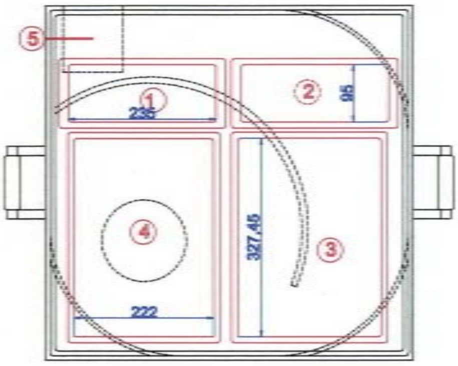

Figure 3: Schematic mapping of the griddle.

3. RESULTS

Following the procedure described above, five experiments were performed. The average values for all parameters will be presented in this section. Figure 4 shows the typical biomass feed rate during an experiment. Initially 900g were fed in the combustion chamber and ignited. More 120g were added 20 minutes after the ignition, following, 2 more loads of 120 g of biomass were added after 60 and 80 minutes after ignition. Biomass feeding rate impacts directly on the exhaustion gas temperature as shown in Figure 5. The combustion occurs with excess of air. The Figure 4 allows the calculation of the mass flow rate of biomass was 9.07g/min during the first 10 minutes and 544g/h as the average experiment mass flow rate. The total biomass consumption was 1.27 kg.

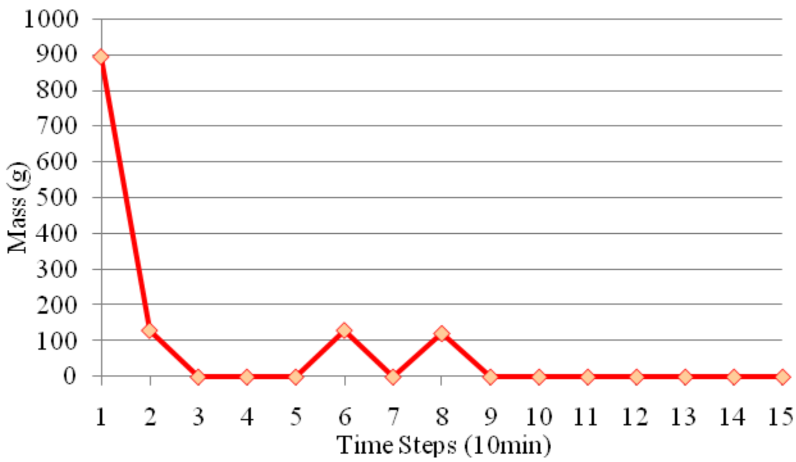

Figure 4: Biomass feeding intervals

Figure 5 also shows the water temperature behaviour within each aluminium tray. It is noted that the temperatures in the trays are limited by the its water boiling temperature.

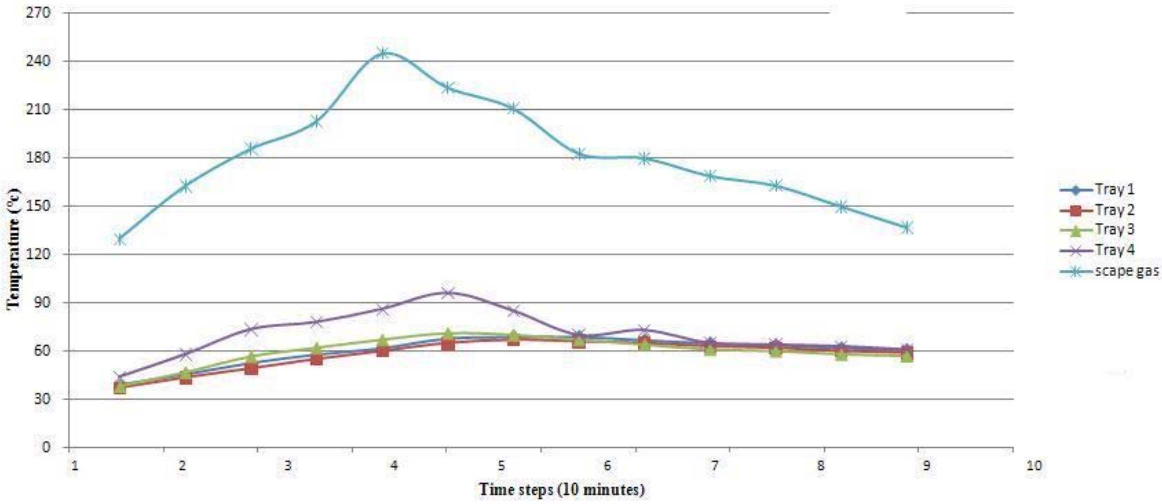

Figure 5: Average temperature of the water in the trays

The **Table 3** presents all the data used to calculate the efficiency using Eq.(1).

Table 3: Data used to calculate the efficiency

Parameters	Unit	Data collected
Description		
Biomass		
Biomass of feeding	kg	1.27
Residual ash	kg	0.13
Biomass consumed	kg	1.25
High Heating Value	kJ/kg	20027.8
Low Heating Value	kJ/kg	18805.44
Biomass moisture content	%	10
Water		
Average of the initial mass of water	kg	4.19
Average of the final mass of water	kg	2.97
Average of the mass of water evaporated	kg	1.22
Water specific heat	kJ/kg°C	4.184
Initial temperature of the water	°C	30
Boiling temperature	°C	100
Latent heat of water	kJ	2259.36
Trays		
Areas		
Tray 1	m²	0.022
Tray 2	m²	0.022
Tray 3	m²	0.07
Tray 4	m²	0.07
Total area	m²	0.19
Mass average		
Tray 1- mass without water	kg	0.11
Tray 1- mass with water	kg	0.68
Tray 1- mass with the remaining water	kg	0.44
Tray 2- mass without water	kg	0.11
Tray 2- mass with water	kg	0.74
Tray 2- mass with the remaining water	kg	0.49
Tray 3- mass without water	kg	0.07
Tray 3- mass with water	kg	1.79
Tray 3- mass with the remaining water	kg	4.63

Tray 4- mass without water	kg	0.27
Tray 4- mass with water	kg	1.73
Tray 4- mass with the remaining water	kg	0.89
Griddle (top plate of the stove)		
Thermal conductivity		
Area	m²	0.32

Efficiency (%)	28.57

Considering only the stoves that use wood as fuel, the Ecofogão performance is satisfactory, with efficiency around 28% determined by the test of boiling water. The Figure 6 compares the performance of Ecofogão with performances of various types of stoves, submitted by Nogueira and Lora (2003).

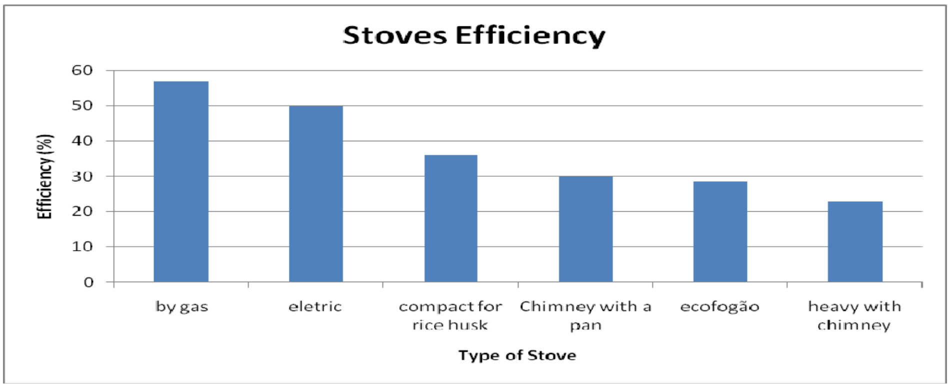

Figure 6: Efficiency of different types of stove in relation to Ecofogão

4. CONCLUSIONS

It can be noted that the efficiency of Ecofogão is below the performance of the gas stoves (57%) and the electric stove (50%), but very close to the type stoves without chimney for a pan (30%) and compact model for Bark of Rice (32 - 36%), and is higher than the stoves of "Three stones" (7 - 10%), with heavy stove chimney (15 - 23%) and without stove chimney (18 - 22%).

Besides that, the temperature of gas comes out from chimney is higher than environment temperature, so that it can be used as an energy source, for example, supporting warm water production through a tube or serpentine system or even increase the size of the plate.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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