Evaluation of the energy efficiencies of commonly available biomass fuels in Uganda in a "Champion-2008" Top Lit Updraft gasifier stove

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Abstract

The Project was concerned with the evaluation of the energy efficiencies of commonly available biomass fuels in Uganda in a "Champion-2008" Top Lit Updraft (TLUD) gasifier stove. Selected biomass fuels included; Eucalyptus wood from plantations, maize cobs (agro-waste), papyrus, spear grass, non-carbonized briquettes (agro-waste and sawdust) and off-grade jatropha seeds. Moisture content measurement of biomass fuels was determined using oven-dry method. The energy efficiencies of the biomass fuels in the "Champion-2008" TLUD gasifier stove lied between 12 and 19%. Maize cobs had the highest energy efficiency of 18.40% and spear grass had the lowest of 12.64%. Maize cobs and papyrus were not significantly different from Eucalyptus wood. Non-carbonized briquettes and off-grade jatropha seeds had a higher operation time compared to the rest of the selected biomass fuels though faced with a problem of higher starting time but able to perform when started. The results obtained indicate that a variety of biomass fuels in Uganda can perform well in the "Champion-2008" TLUD gasifier stove, thus the need for adoption to combat deforestation problem.

Key words: Biomass, Energy efficiency, TLUD gasifier stove, Uganda, CREEC.

1.0 Introduction

Biomass energy is of great interest for global development. About half of the world's population depends on fuel wood for cooking and other domestic uses (Twidell and Weir, 1986). Biomass (firewood and charcoal) plays a very significant role in Uganda's energy supply constituting over 90% of total energy consumption (MEMD, 2002). Biomass provides almost all the energy used to meet basic needs of cooking and water heating. In Uganda, the main source of energy for rural households is wood fuel which accounts for about 90% for cooking (MFPED, 1999).

Fuel wood requirements have contributed to the degradation of forests as wood reserves are depleted at a rapid rate in many regions (MEMD, 2002). Charcoal consumption increases at a rate of 6% per annum (MEMD, 2002). Heavy dependence on wood and charcoal has resulted into deforestation.

The majority of stoves in Uganda mainly use one type of biomass fuel such as fire wood and charcoal stoves.

The "Champion-2008" TLUD gasifier stove being a new technology in Uganda required assessment of its performance using commonly available biomass fuels, some typically not being used for cooking like maize cobs. There was a need for use and efficient utilization of a variety of biomass materials so as to reduce deforestation.

The main objective of the study was to evaluate the energy efficiencies of commonly available biomass fuels in Uganda in the "Champion-2008" TLUD gasifier stove. The specific objectives were; to determine the bulk density, burning rate and specific fuel consumption of the biomass fuels and to determine the energy efficiencies of the different biomass fuels when used in the "Champion-2008" TLUD gasifier stove. The project was limited to a specific "Champion-2008" TLUD gasifier stove. There was only variation in the biomass fuels and other factors were kept constant.

Biomass is organic carbon material that reacts with oxygen in combustion and natural metabolic processes to produce heat (Twidell and Weir, 1986). Thermal properties of biomass include; Energy content, moisture content, volatile matter content, bulk density, particle size and size distribution.

Biomass gasification is the incomplete combustion of biomass for example wood and agricultural residues to produce carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2) and methane (CH_4). The mixture of carbon monoxide and hydrogen is called "Producer gas". The main gas produced from biomass gasification is the producer gas which can be oxidized to produce thermal or electrical energy (Quaak et al, 1999).

Micro-gasification is the gasification of biomass in small devices for example the TLUD gasifier stove**.** Combustion of biomass is cleaner when the air is well mixed with only combustible gases. The creation of combustible gases that are separate from the combustion of those gases is characteristic of a true gasifier (Anderson et al, 2007).

The TLUD gasifier stove is a device which carries out incomplete combustion of biomass to produce pyrolytic gases (carbon monoxide, hydrogen, carbon dioxide and methane) which are oxidized to produce a hot flame of about 800^0C and leaving charcoal as a bi-product. The TLUD gasifier stove does not release smoke during system operation and reduces respiratory diseases such as lung cancer thus environmentally friendly. The TLUD gasifier stove is used in processes which require thermal energy especially cooking and water heating (Anderson, 2009).

The TLUD gasifier stoves fall into two main categories; forced air and natural draft. TLUD gasifiers operate with batches of fuel (Anderson et al, 2007). The "Champion-2008" TLUD gasifier stove has the following components; Fuel chamber, primary air inlet, fuel grate, outer cylinder, handle, spacers, concentrator lid with a handle, fuel cylinder extension and riser/coupler (Anderson, 2009).

2.0 Methodology

The biomass fuels used in the “Champion-2008” TLUD gasifier stove for energy efficiency evaluation were; wood (Eucalyptus grandis), maize cobs, papyrus, spear grass, non-carbonized briquettes (agro-waste and saw dust) and off-grade jatropha seeds.

The apparatus used involved the following;

- “Champion-2008” TLUD gasifier stove with dimensions; Fuel cylinder (diameter = 150mm, height = 230mm), outer cylinder (diameter = 195mm, height = 340mm), riser (height = 127mm, diameter = 155mm) and primary air inlet (width = 55mm, height = 55mm).

Figure 2.1: The “Champion-2008” TLUD gasifier stove

- 5 litre aluminum saucepan.
- 2.5 litres of water.
- Steel stand

Figure 2.2: Steel stand

- Thermometer with 0.1 ^{0}C accuracy.

Figure 2.3: Digital thermometer

- Weighing scale with 1 g accuracy.

Figure 2.4: Weighing scale

- Stop clock with 1 second accuracy.

Figure 2.5: Stop clock

- 40 g wood starter

The “Champion-2008” TLUD gasifier was used to heat 2.5 litres of water in a 5 litre aluminium saucepan using the selected biomass fuels.

Figure 2.6: Set up of the experiment

The parameters which were measured were; mass of biomass fuel used, ambient air temperature, time of starting, operation time, water temperature and mass of charcoal produced.

The mass of biomass fuels used in the "Champion-2008" TLUD gasifier stove were; Eucalyptus wood (963g), maize cobs (591g), papyrus (366g), spear grass (169g), non-carbonized briquettes (2050g) and off-grade jatropha seeds (1443g).

The temperature of the water was recorded after every 2 minute interval. The water was allowed to reach boiling point and continue boiling till all the biomass fuels were used up.

The moisture content of each biomass fuel was determined using the oven-dry method. Each biomass fuel was first weighed and put in an oven for 6 hours at a temperature of 110 ^{0}C. Moisture content was obtained using the following equation;

$$MC_{dry} = \frac{M_i - M_f}{M_f} \times 100 \text{ .... (2.1)}$$

Where; $\mathbf{MC_{dry}}$ = Moisture content dry basis (%), $\mathbf{M_i}$ = Initial weight of biomass (g) and $\mathbf{M_f}$ = Final weight of biomass (g)

Bulk density of each biomass fuel was calculated using the formula below;

$$D_b = \frac{M}{V_b} \text{ .... (2.2)}$$

Where; $\mathbf{D_b}$ = bulk density, **M** = mass of biomass fuel and $\mathbf{V_b}$ = bulk volume of the fuel cylinder.

The bulk volume of the fuel cylinder of the "Champion-2008" TLUD gasifier stove occupied with the biomass fuel was 3712.5 cm^3 which was constant in all experiments.

The specific fuel consumption for each biomass fuel was determined.

$$SFC = \frac{M}{V_w} \text{ .... (2.3)}$$

(Shell Foundation, 2008)

Where; **M** = mass of biomass fuel used (g) and $\mathbf{V_w}$ = volume of water evaporated (cm^3)

The burning rate for each biomass fuel in the "Champion-2008" TLUD gasifier stove was determined. The rate at which biomass fuel burns down depends also on the unit size.

$$B_r = \frac{M}{t} \text{ .... (2.4)}$$

(Shell Foundation, 2008)

Where; $\mathbf{B_r}$ = burning rate (g/min), **M** = mass of biomass fuel (g) and **t**= time taken (minutes)

The proportion of charcoal produced was determined from the mass of biomass fuel used and mass of charcoal produced.

$$C_p = \frac{M - M_c}{M} \times 100 \text{ .... (2.5)}$$

Where;

$\mathbf{C_p}$ = proportion of charcoal (%), **M** = mass of biomass fuel (g) and $\mathbf{M_c}$ = mass of charcoal (g)

The energy efficiency for each biomass fuel in the "Champion-2008" TLUD gasifier stove was also determined. The energy efficiency is the ratio of energy output to energy input (Still. D et al, 1996).

$$E_b = \frac{E_{out}}{E_{in}} \times 100 =$$

$$\frac{m_w c(T_f - T_i) + m_s L}{(m_b C_v - m_c C_{v1})} \times 100 \text{ .... (2.6)}$$

Where; m_b= mass of biomass fuel (kg), m_c= mass of charcoal produced (kg), C_v = calorific value of the biomass fuel (kJ/kg), C_{v1}= calorific value of charcoal produced (kJ/kg), m_w = mass of water (kg), **c** = specific heat capacity of water = 4.185 kJ/kgK, T_i = initial temperature of water (K), T_f = final temperature of water (K), m_s = mass of steam (kg), **L** = latent heat of vaporization of water = 2260 kJ/kg, E_{in} = energy input (kJ), E_{out} = energy output (kJ) and E_b = biomass energy efficiency (%)

Charcoal from wood has roughly 150% the calorific value of wood (Shell Foundation, 2008).

Assuming C_{v1}= 1.5C_v for all the biomass fuels;

$$E_b = \frac{m_w c(T_f - T_i) + m_s L}{(m_b - 1.5 m_c) C_v} \times 100 \text{ .... (2.7)}$$

3.0 Results and Discussions

Moisture content for all the biomass fuels was meant to be constant but it was not possible to achieve practically. The moisture content for all the biomass fuels lied between 8 and 15%. Jatropha seeds had the lowest moisture content of 8.78% and maize cobs had the highest of 14.96%. The higher the moisture content of the biomass fuel the lower the biomass energy efficiency.

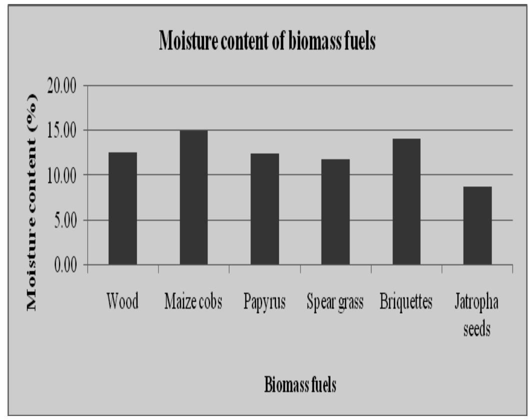

Figure 3.1: Graph of moisture content of biomass fuels used

Least Significant Difference (LSD) test was used to obtain the significance difference between the treatment means of the biomass fuels in the "Champion-2008" TLUD gasifier stove. Eucalyptus wood was taken as a control since it is the main biomass fuel used in Uganda.

$$LSD_a = t_a \left[\frac{2S^2}{R} \right]^{1/2} \text{ .... (2.8)}$$

Where; LSD_a = Least significant difference at a-level of **significance,** t_a = Tabular t value at a-level of significance, S^2 = Error MS from the ANOVA table, **R** = Number of replications.

There was variation in bulk density of the biomass fuels. Non-carbonized briquettes had the highest bulk density of 0.5522 g/cm^3 and Spear grass had the lowest bulk density of 0.0455g/cm^3. The bulk densities for wood, maize cobs, papyrus and spear grass were relatively low and lied between 0.05 and 0.26g/cm^3.

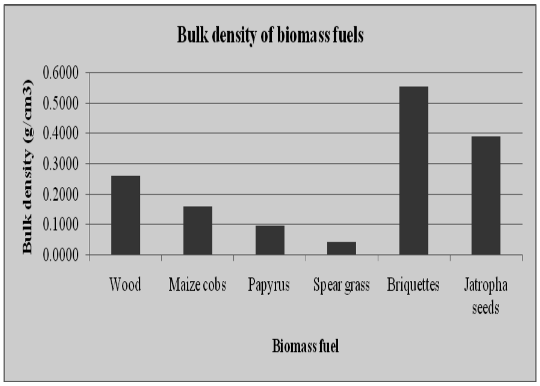

Figure 3.2: Graph for bulk density of biomass fuels

Starting time of the biomass fuels is related to bulk density. The lower the bulk density of the biomass fuel, the less time of starting and vice versa. Spear grass had the lowest starting time of 0.82 minutes and briquettes had the highest starting time of 22.50 minutes.

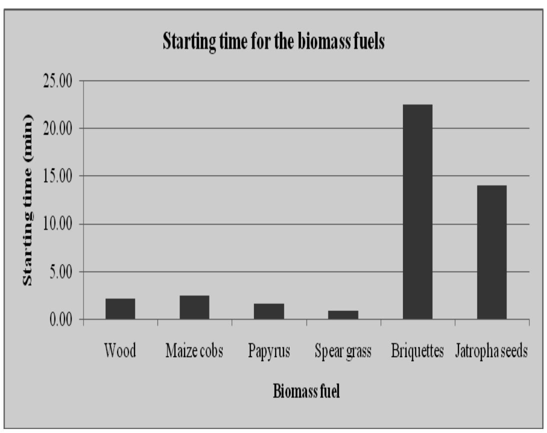

Figure 3.3: Graph of starting time for biomass fuels

The operation time of the biomass fuels also has an effect on the biomass energy efficiency of the biomass fuels in the "Champion-2008' TLUD gasifier stove. There was variation in the operation time of the biomass fuels in the "Champion-2008" TLUD gasifier stove. Jatropha seeds had the highest operation time of 149.5 minutes and spear grass had the lowest operation time of 4.0 minutes.

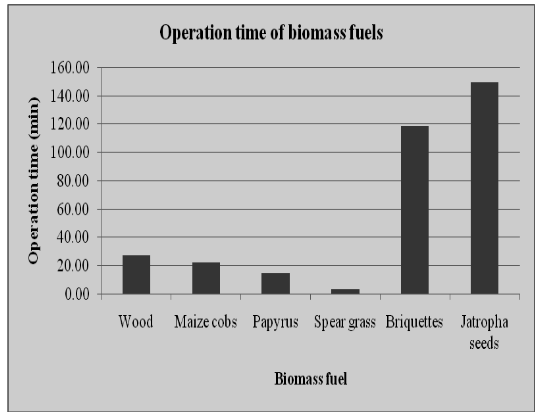

Figure 3.4: Graph of operation time of the biomass fuels

Papyrus and spear grass did not boil water. Papyrus heated water up to 89.5^{0}C in 16 minutes and spear grass heated water up to 54.1^{0}C in 4 minutes. Wood had the lowest time to boil of 10 minutes and jatropha seeds had the highest time to boil of 66.5 minutes. This shows that jatropha seeds absorb less energy per unit time in the "Champion-2008" TLUD gasifier stove compared to wood.

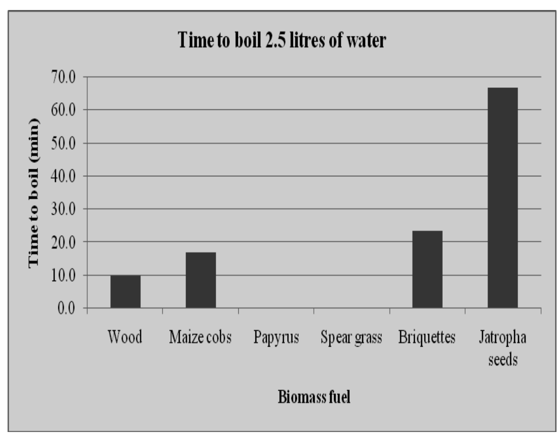

Figure 3.5: Graph for time to boil 2.5 litres of water

Specific fuel consumption is inversely proportional to the bulk density of the biomass fuel. The higher the bulk density of the biomass fuel the lower the specific fuel consumption and vice versa. Spear grass had the highest SFC of 11.23 g/cm^3 and jatropha seeds had the lowest SFC of 0.62 g/cm^3.

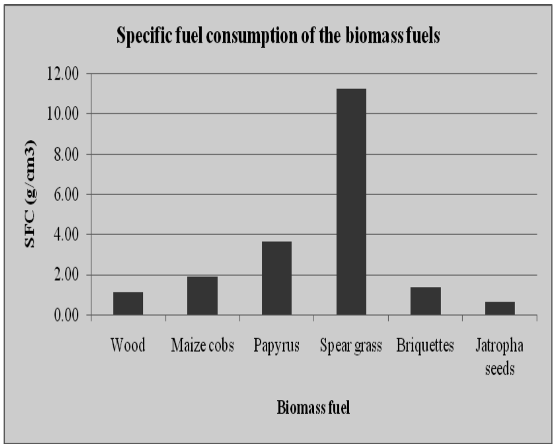

Figure 3.6: Graph for SFC of the biomass fuels

spear grass had the highest burning rate of 42.25 g/min and jatropha seeds had the lowest burning rate of 9.67 g/min. Burning rate is affected by the bulk density of the biomass fuel. The lower the bulk density of the biomass fuel in the "Champion-2008" TLUD gasifier stove the higher the burning rate and vice versa.

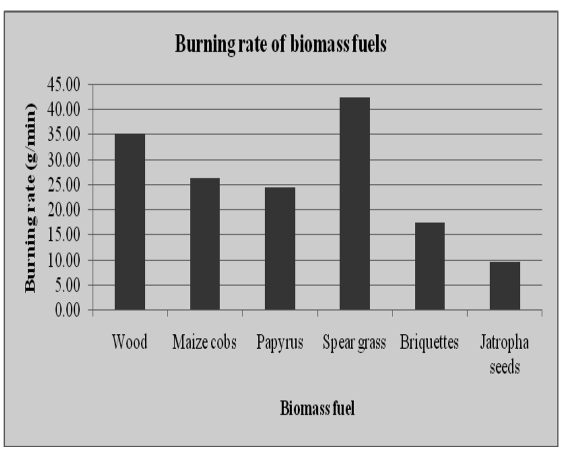

Figure 3.7: Graph showing the burning rate of biomass fuels

Charcoal proportion from the biomass fuel is directly proportional to the bulk density and also has an effect on the biomass energy efficiency. Jatropha seeds produced the largest proportion of charcoal of 23.48% from the biomass fuel and spear grass produced the lowest charcoal proportion of 8.43%.

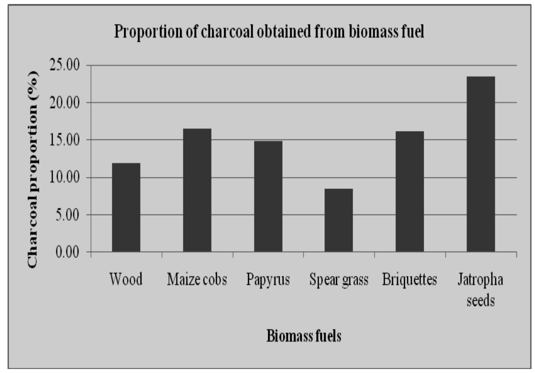

Figure 3.8: Graph for proportion of charcoal obtained from biomass

Energy efficiency has an effect on the performance of the biomass fuels in the "Champion-2008" TLUD gasifier stove during a thermal application for example cooking. It shows how the "Champion-2008" TLUD gasifier stove can save energy from the different biomass fuels when used in it. The biomass energy efficiency of the biomass fuels lied between 12 and 19%. Maize cobs had the highest biomass energy efficiency of 18.40% and spear grass had the lowest biomass energy efficiency of 12.64%.

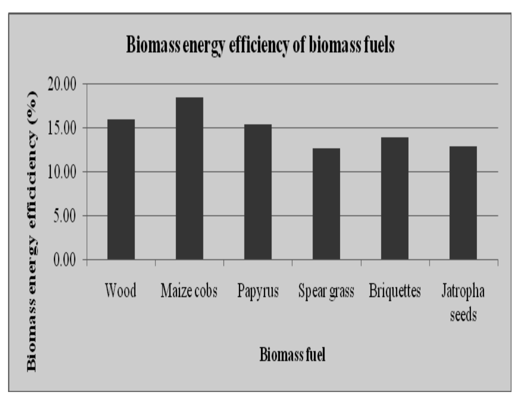

Figure 3.9: Graph of biomass energy efficiency

Property	M	P	S	B	J
MC_{dry} (%)	1	3	2	1	1
t_s (min)	3	3	3	1	1
t_o (min)	3	3	1	1	1
t_b (min)	3	2	2	2	1
SFC (g/cm^3)	3	2	1	3	3
B_r (g/m)	1	1	1	1	1
C_p(%)	2	3	2	2	1
E_b(%)	2	3	1	2	1

Table 3.1: Significant difference of the selected biomass fuels from Eucalyptus wood

Where; **M**= maize cobs, **P**= papyrus, **S**= spear grass, **B**= non-carbonized briquettes, **J**= off-grade jatropha seeds, $\mathbf{MC_{dry}}$= moisture content dry basis, $\mathbf{t_s}$= time of starting, $\mathbf{t_o}$= operation time, $\mathbf{t_b}$= time to boil 2.5 l water, **SFC**= specific fuel consumption, $\mathbf{B_r}$= burning rate, $\mathbf{C_p}$= charcoal proportion, $\mathbf{E_b}$= biomass energy efficiency, **1**= highly significant, **2**= Significant and **3**= non significant.

4.0 Conclusions

The results from maize cobs and papyrus were not significantly different from Eucalyptus wood basing on; moisture content, starting time, operation time, time to boil 2.5 litres of water, specific fuel consumption, burning rate, charcoal proportion and biomass energy efficiency.

Non-carbonized briquettes and off-grade jatropha seeds had lower burning rate and higher operation time compared to the rest of the selected biomass fuels which are important at increasing the biomass energy efficiency. They were faced with a problem of higher starting time and still capable of being used in the "Champion-2008" TLUD gasifier stove.

The energy efficiencies of the biomass fuels in the "Champion-2008" TLUD gasifier stove lied between 12 and 19%. Maize cobs had the highest energy efficiency of 18.40% and spear grass had the lowest of 12.64%. In general, a variety of biomass fuels in Uganda can perform well in the "Champion-2008" TLUD gasifier stove since the selected biomass fuels were able to perform.

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