

Yield and Chemical Characteristics of Charcoal Produced by TLUD-ND Gasifier Cookstove Using Eucalyptus Wood as Feedstock

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ABSTRACT

A Top-Lit UpDraft Natural Draft (TLUD-ND) gasifier cookstove primarily pyrolyses biomass feedstock and then burns combustible gases separately to provide heat for cooking while giving out charcoal as a byproduct. In this study, the charcoal produced from water boiling test (WBT) conducted on the stove was analyzed for its suitability for domestic use. Three fuel sample sizes were used and the charcoal produced was then characterized by proximate analysis to observe the effect of feedstock size on yield and characteristics of the charcoal produced. The results showed a mean charcoal yield of 18 % with slight variation over the range of considered feedstock size. The produced charcoal had average proximate analysis of; fixed carbon (FC) = 86.2%, volatile matter (VM) = 12% and Ash = 1.8%. When this is compared with traditional kilns having typical yield not exceeding 20%, it has been shown that charcoal from TLUD-ND realizes slightly higher energy recovery due to high fixed carbon content. Nevertheless, the low volatile matter content of the charcoal makes it friable making handling difficult. Moreover, the energy transferred to cooking pot was regarded as net additional fuel saving attained by the stove compared to traditional charcoal kilns.

Keywords: Charcoal yield, Energy recovery, Gasifier stove, Proximate analysis, Pyrolysis

1.1 INTRODUCTION

Traditional methods of charcoal production in developing countries realize gravimetric yield of 20% or less, and modern industrial technology offers yields of 25-37% (Antal *et al.*, 1996). Improved charcoal stoves made from pottery with good insulation are capable of delivering up to 30% efficiency. When these efficiencies of charcoal production and use are combined taking the difference in their heating values into consideration, cooking with charcoal realizes energy transfer of 10% or less to the end-use. Thus, even given the high efficiencies of charcoal stove, the use of charcoal for cooking is always less energy efficient than cooking with wood since a well managed open fire has an efficiency of 10-15% (Charles and Essel, 2000). The reason is that about 30% energy recovery corresponding to the 20% gravimetric yield implies large energy loss (over 70%) due to the volatiles liberated in the form of smoke in the kiln site while making charcoal (Quaak *et al.*, 1999). Conversely, TLUD-ND gasifier cookstove first utilizes the volatile matter for cooking and then gives charcoal as an output; ideally allowing 100% availability of the primary energy content of the feedstock for cooking. Hence, the main objective of this paper is to assess the competence of TLUD-ND gasifier cookstove as an alternative charcoal making apparatus in saving fuelwood.

1.2 Equipment and Material

1.2.1 TLUD-ND Gasifier Cookstove

TLUD-ND gasifier cookstove is a newly introduced alternative cooking stove developed to provide cleaner and better controlled gas for cooking (Reed and Larson, 1996). Once the fuel gets lit on top, the stove first pyrolyses feedstock with the help of limited primary air supply; thereby generating combustible gas which is later combusted when mixed with secondary air to

provide heat for cooking as illustrated in Figure 1. Fuel tank of the stove had a volumetric capacity of $1.6 \times 10^6 \text{ mm}^3$ at full load. The stove is also fitted with a post-cooking-pot chimney 640 mm high and 80 mm in diameter to enhance natural draft.

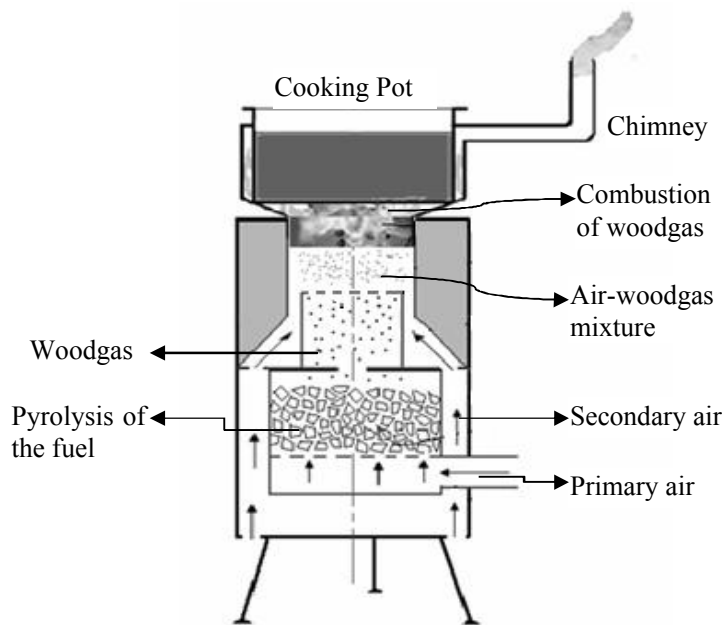


Figure 1: A schematic illustration of TLUD-ND gasifier stove used in the study

1.2.2 The Feedstock: Eucalyptus

Eucalyptus is a fast growing woody plant capable to grow in a wide range of climate and soil characteristics including water scarce areas. Reports from previous studies have revealed that calorific value of eucalyptus is less affected by age and species (Bekele and Lemenih, 2004), making eucalyptus worth investigating as feedstock for gasifier stove since the result obtained shall represent a wide variety of species.

Feedstock used in the experiments was prepared in cubes of three different sizes ($A=25 \times 25 \times 25 \text{ mm}^3$, $B=20 \times 20 \times 20 \text{ mm}^3$ and $C=15 \times 15 \times 15 \text{ mm}^3$). The feedstock sizes were selected so as to fall within the recommended limit $5 \times 10 \times 20 \text{ mm}$, plus or minus half of each dimension (Anderson and Reed, 2004; Reed and Larson, 1996) which was established for similar stoves.

The average moisture content of the feedstock used in this study was 8.9% on dry basis. It had also proximate analysis: FC =23.2%, VM =75.1% and Ash=1.7%, on dry basis and corresponding average lower heating value (LHV) of 16.9MJ/kg.

1.3 Methodology

The experimental study conducted involved a total of twelve stove tests that have been used to analyze the stove under possible combination of three fuel particle sizes, presence and absence of chimney, and full load and part load conditions as shown in Table 1. The amount of feedstock used for each WBT run was measured using digital weighing balance. The remaining charcoal at the end of each test run was first weighed to determine yield and then chemically characterized by proximate analysis according to ASTM D 1762-84 procedure. Higher heating value (HHV) of the charcoal was then calculated based on its proximate analysis.

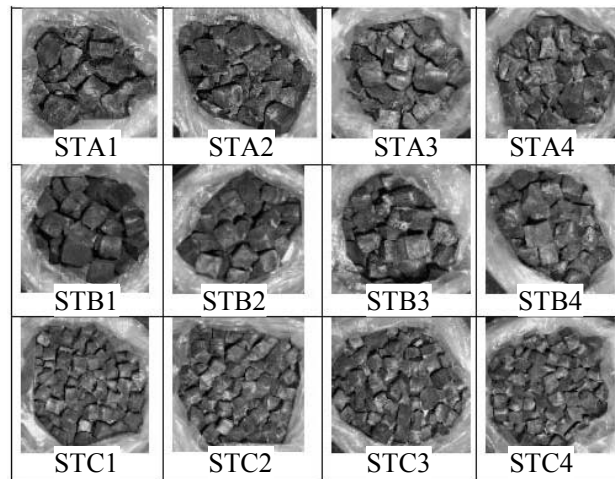
Table 1: Nomenclature of stove tests

Fuel particle size	Without chimney		With chimney	
	Part load	Full load	Part load	Full load
A	STA1	STA2	STA3	STA4
B	STB1	STB2	STB3	STB4
C	STC1	STC2	STC3	STC4

2.0 RESULTS AND DISCUSSION

2.1 Physical Characteristics of Charcoal

Physical characteristics of charcoal were presented both by visual observation and dimensional measurement using a Vernier Caliper. The appearance of formed charcoal was as shown in Figure 2. Table 2 describes the changes occurred on fuel particles after they have been pyrolyzed. It can be observed that larger particles showed more deformation than smaller particles. This was due to easy air movement through wider space between fuel particles which resulted in partial combustion consuming part of it. The charcoal particles showed more shrinkage across the grain direction compared to the direction along the grain.

**Figure 2:** Pictures of charcoal particles from respective stove tests**Table 2:** Visual observations and measurements from the produced charcoal

Fuel particle size	Uniformity	Deviation from original cubic shape	Appearance of ash on surface	Average final size [mm x mm x mm]
A	Wide variation	Deformed: original shape has almost been lost.	Some ash noticeable	21x20.3x19.7
B	Little variation	Larger portion of the charcoal has maintained original cubic shape with minor exceptions.	Very little trace	18x16.3x16
C	Almost uniform	The deformation was not considerable; Original shape has almost been maintained	Minimal	13.17x12.5x12.2

2.2 Proximate Analysis of Charcoal

Proximate analysis test was conducted on the formed charcoal to enable the determination of its heating value. The average proximate analysis of charcoal from respective feedstock size is shown in Figure 3. The volatile matter content was found to be too low compared to the recommended value of 20-40% required for domestic cooking. However, this type of charcoal has acceptable quality to be used for metallurgical process since the recommended value is 85-90% fixed carbon (Antal *et al.*, 1996). The fact that the produced charcoal has volatile matter less than 30% makes it more friable with subsequent difficulty in handling and transportation (FAO, 1987).

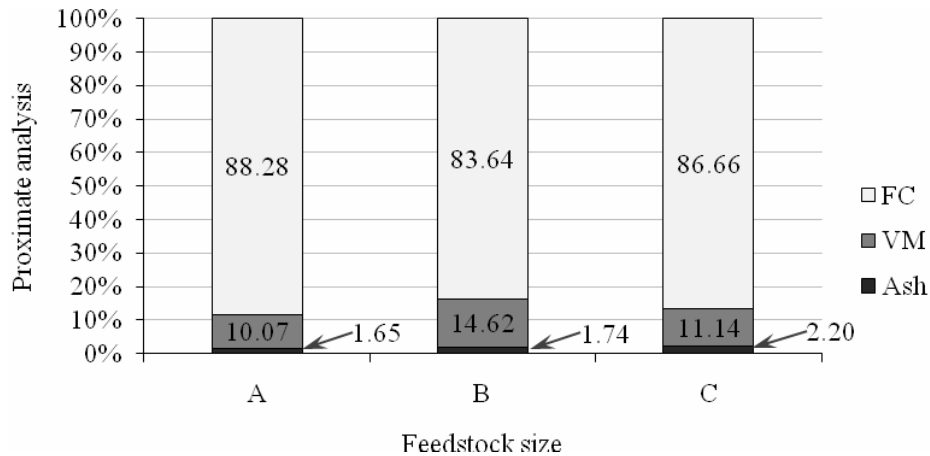


Figure 3: Average proximate analysis for charcoal from the three feedstock sizes

HHV of the charcoal was calculated based on its proximate composition as per the correlation developed by Parikh *et al.* (2005). The correlation enables to estimate HHV of dry biomass with an average absolute error of 3.74% and bias error of 0.12% with respect to measured value. Since hydrogen content of charcoal is negligible (Baker *et al.*, 1991), LHV of charcoal was assumed to be the same with HHV.

$$HHV = 0.3536(FC) + 0.1559(VM) - 0.0078(ASH) \quad (1)$$

Hence, the average HHV of charcoal was found to be 32.33 MJ/kg with a standard deviation of only 0.47 MJ/kg. Thus showing more consistent value compared to charcoal from conventional kilns that show wider range of variation, 25 – 32% (Quaak *et al.*, 1999).

1.4.3 Charcoal Yield and Energy Recovery

Charcoal yield is the gravimetric ratio of charcoal restored from the stove to the dry weight of feedstock admitted to the stove at the start of each WBT run.

$$Charcoal\ yield(y_{ch}) = \frac{M_{ch}}{M_f(1 - MC_{wb})} \times 100 \quad (2)$$

Where: M_{ch} =Dry weight of charcoal, M_f = weight of feedstock and MC_{wb} =moisture content of feedstock on wet basis.

The calculated value of charcoal yield from each of the twelve test run is graphically presented in Figure 4 below.

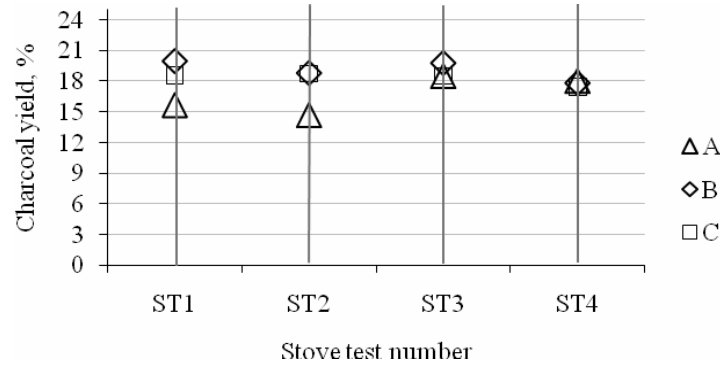


Figure 4: Charcoal yield obtained from each stove test for three fuel sizes

The calculated mean value of charcoal yield from the twelve tests was $18.05 \pm 1.53\%$. Moreover, analysis by ANOVA showed no significant difference in the charcoal yield among the stove test runs with different fuel particle sizes at significance level of 5%. Nonetheless, the absolute mean difference showed that the charcoal yield from big sized feedstock particles is slightly lower than the smaller particles. This has happened due to occurrence of some combustion instead of pyrolysis which led to relatively higher ash and high level of shape distortion of the recovered charcoal for bigger feedstock as shown in Table 2.

The fact that charcoal yield is almost constant (standard deviation = 1.53%) implies that TLUD-ND cookstove is capable of maintaining nearly constant charcoal yield unlike wide variation in the case of traditional charcoal kilns.

Percent energy recovered in charcoal was also calculated using Equation 3.

$$\text{Percent energy recovered in charcoal } (E_{ch}) = \frac{M_{ch} \times HHV_{ch}}{M_f \times LHV_f} \times 100 \quad (3)$$

Where: HHV_{ch} = HHV of charcoal and LHV_f = LHV of feedstock

The calculated mean value of energy recovered from twelve stove tests was $31.75 \pm 2.40\%$. The percentage energy recovered in charcoal is graphically shown in Figure 5. Since energy recovery from some stove tests exceeds 30%, the study shows that TLUD-ND gasifier cookstove has better performance than many traditional charcoal kilns as a charcoal maker.

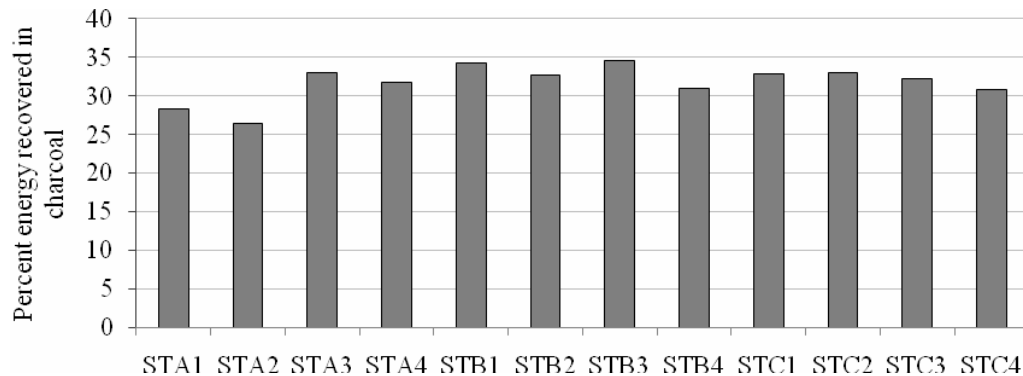


Figure 5: Percentage of wood energy recovered in charcoal

The high energy recovery achieved was mainly due to large proportion of fixed carbon in the charcoal.

Further analysis of thermal efficiency has also shown that 10-15% of the energy that has been contained in the feedstock was transferred to the water in the cooking pot.

3.0 CONCLUSION

Besides consistent value of yield ($18.05 \pm 1.53\%$) compared to traditional kilns (10-20%), the energy recovered was slightly higher than that of traditional kilns due to high calorific value of the charcoal resulted from high fixed carbon content. Along with its competent yield and quality of charcoal, TLUD-ND gasifier cookstove has proved its fuel saving capability by utilizing the pyrolysis gas for cooking. Hence, the 10-15% energy transferred to cooking pot is a net fuelwood saving offered by the stove.

Although the produced charcoal is difficult to handle due to its friability caused by low volatile matter content, it is quite suitable to use it in an adjacent charcoal stove to avoid problems in handling and thereby taking advantage of its large LHV which otherwise would have been lowered due to absorption of moisture.

Furthermore, the appropriate way to maximize benefits from TLUD-ND cookstove as charcoal maker would be to use it in institutions like universities, military camps, boarding schools and hotels which use both firewood and charcoal for cooking.

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