Performance Appraisal of the Casamance Kiln as a Replacement to the Traditional Charcoal Kilns in Uganda

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ABSTRACT
Charcoal production is an important activity in Uganda's energy mix. The Government of Uganda, through the Ministry of Energy and Mineral Development (MEMD), is advancing promotion of energy efficiency in the charcoal production process to ease on the rampant deforestation. In this research, the Casamance kiln is appraised against the Uganda traditional kilns to gauge their effective performance. The Casamance kiln is known to be one of the most adaptable carbonizers for local charcoal producers. The objective of this research was to produce an affordable and efficient Casamance, which is easy, not only for the charcoal producers to operate, but also for the local metal fabricators to manufacture. Tests were carried out under different conditions in order to come up with the most suitable operating conditions for charcoal production. The design criteria for the kiln was based on the conditions that favour the formation of organic vapours (tars) and their residence time in the flow tube (chimney). For affordability, the kiln was produced from locally available materials. The different conditions imposed during the experimentation with the kilns included variation in kiln size and moisture content. In all cases, the performance of the Casamance kiln was ahead of the traditional kilns in terms of conversion efficiency, quality of charcoal and duration of carbonization. The Casamance kiln uses only half of the wood used by the traditional kiln to produce the same amount of charcoal, hence resulting in significant wood fuel savings.

Key words: Casamance, Charcoal, Efficiency improvement.

1.0 INTRODUCTION
Biomass is the main source of energy in Uganda, contributing about 94% of all energy consumed, followed by petroleum and electricity. The bulk of this biomass is consumed in rural and poor households which often cannot afford the high costs of modern energy services like electricity and LPG. Of the total biomass consumed, wood fuel accounts for about 80%, charcoal 10%, and crop residues 4% (MEMD, 2007).

Charcoal is therefore an important fuel and its production is an important economic activity. The sector provides employment to a number of semi-skilled and unskilled labourers at different stages of production, transportation and distribution at the various retail outlets. Per capita consumption of charcoal in Uganda is 4 kg/year and 120 kg/year for rural and urban areas respectively. Total biomass (firewood and charcoal) demand for households was 22.2 million tons in 2006. Small scale industries account for about 20 percent of total biomass use, adding a further 5.5 million tons and bringing the total biomass demand to about 27.7 million tons countrywide (Energy Systems VAR, 2009).

There is lack of knowledge of the best practices in charcoal production. The methods and types of kilns employed in charcoal production are not only inefficient but wasteful in terms of wood fuel charged. A number of initiatives by the Ministry of Energy and Mineral

Development (MEMD), NGOs and the Italian Cooperation through this research have been aimed at addressing issues of efficiency improvement in the charcoal production, marketing and distribution processes. This research is promoting the use of Casamance charcoal kilns as a short term strategy in addressing the rampant deforestation which results from inefficient utilisation of wood fuel for charcoal production. By using the Casamance kiln, significant savings in wood required for kiln charges are made (Nturanabo and Tumuhimbise, 2010).

2.0 OBJECTIVES AND JUSTIFICATION OF THE RESEARCH

The main objective of this research was to improve the efficiency of charcoal production by promoting the use of the Casamance kiln as a replacement to the traditional earth kiln in order to reduce wood waste, improve forest utilization, and meet national energy needs at reasonable prices.

The specific objectives of the research were to:

- design and fabricate an improved earth kiln of the Casamance type from locally available materials;
- measure the technical performance of the improved Casamance model of earth kiln against the traditional earth mound;
- recommend the best practices in charcoal production using the Casamance kiln model suitable for use by rural charcoal producers.

Charcoal consumption in urban centres has continued to increase rapidly due to the increase in population growth (demand for energy) and higher costs for alternative energy sources, especially electricity and gas. This trend is not likely to improve in the foreseeable future.

Moreover, charcoal as a fuel has its own advantages and its production forms an important source of income to the rural dwellers. Charcoal is the preferred form of fuel in the urban centres because it is:

- more affordable compared to electricity, kerosene, or gas;
- more economical than wood to transport long distances;
- occupies less space in the already congested quarters of the urban centres;
- suitable for use in small stoves in the limited space of urban households;
- more energy efficient as its heating value is twice that of wood;
- smokeless and sulphur-free, making it ideal for towns and cities;
- not liable to deterioration by insects and/or fungi.

The low efficiency of charcoal production causes it to be a principal cause of the deforestation of many tropical countries and a contributor to global warming.

3.0 THE SCIENCE OF CHARCOAL PRODUCTION

3.1 The Carbonization Process

The different stages of carbonization are:

- Heating up (drying): from the ambient temperature to 100°C
- Dehydration: between 110 and 220°C
- Exothermic stage which begins at 270°C, reaching 500 to 700°C when carbonization is complete.
- Cooling during which the chimney is removed and the mound is hermetically sealed.

The drying and dehydration stages consist mainly of reducing the water content by first removing the water stored in the wood pores then the water found in the cell walls of wood and finally chemically-bound water.

Preceding the exothermic stage, the pre-carbonization stage (about 200 to 300°C) marks the expulsion of the pyroligneous liquids in the form of methanol and acetic acids and emission of small amounts of carbon monoxide and carbon dioxide. The end of this stage produces charcoal which is in essence the carbonized residue of wood. The last stage in the carbonisation process drives off the remaining volatiles and increases the carbon content of the charcoal (FAO, 1987).

3.2 Charcoal Kiln Efficiency Improvement

Past efforts to improve charcoal production have largely focused on enhancing the efficiency of the carbonisation stages through the design of new charcoal kilns. Table 1 gives a comparison in performance between types of charcoal kilns.

Table 1: Main characteristics of various categories of charcoal kilns
(**Source:** Kristofferson and Bokalders, 1986)

Kiln type	Typical capacity	*Yield, %	Estimated cost ($)	Countries using the kiln
Earth Kilns				
Mound	5 - 100 m^3	10 - 25	Very low	Many developing countries
Casamance	Variable	25 - 31	200	Cameroon, Ghana, Malawi, Senegal
Pit	3 - 30 m^3	30 - 35	Very low	Sri Lanka, Tanzania and other developing countries
Metal kilns				
Mark V	300-400 kg	20 - 25	2000 to 5000	Uganda
Oil drum	12-15 kg	23 - 28	Low	Kenya, the Philippines
Brick kilns				
Beehive and half-orange	9-45 m^3	25 - 35	150 to 1500	Argentina, Brazil and Malawi
Masonry kilns				
Katugo	70 m^3	25 - 30	8000	Uganda
Missouri	350 m^3	25 - 33	15000	USA and other developed countries
Retort kilns				
Cornell	1-3 tons	22 - 33	40000	Norway and other developed countries (smaller prototypes tried in Ghana and Zambia)
Lambiotte	3,000-20,000 t/a	30 – 35	0.5 to 2 million	Australia, Côte d'Ivoire, France and other developed countries

*Yield: On dry-wood weight basis (at variable moisture contents)

The low efficiency of conventional charcoal kilns and retorts can be explained from knowledge of the pyrolysis reactions. Pyrolysis abruptly transforms wood into a tarry vapour containing a complex mixture of organic compounds and non-condensable gases (including CO_2, CO, H_2, CH_4, and heavier hydrocarbons) between 250 and 400°C. The tarry vapours quickly escape the heated region of the reactor without establishing equilibrium and without forming charcoal. These observations can be represented in the following approximate stoichiometric reaction for the carbonization of wood at 400°C:

$$2C_{42}H_{60}O_{28} \rightarrow 3C_{16}H_{10}O2 + 28H_2O + 5CO_2 + 3CO + C_{28}H_{34}O_9 \quad (1)$$

The yield of charcoal ($C_{16}H_{10}O_2$) in Equation (1) is 36.7 wt %, and the tarry vapours ($C_{28}H_{34}O_9$) constitute a significant loss of carbon. Transforming these tarry vapours into charcoal makes economic sense. Moreover, a high carbonization efficiency reduces the amount of feedstock consumed, the transportation costs of the feedstock to the kiln, and the release of the tarry vapours into the environment with their serious impacts on air and water quality (Raveendran, 1996).

3.3 Factors that affect charcoal yield and quality

The carbonisation process which determines the charcoal quality and quantity (yield) is influenced by the wood species, size and moisture content. For sustainable charcoal production, energy plantations are managed on growth rate to optimise charcoal properties. Wood species which produce dense charcoal, like eucalyptus, are favoured for this purpose. What counts in the long run is the mass of saleable charcoal produced per unit mass of wood.

Moisture in the wood charged into the kiln has to be evaporated by burning extra wood and this lowers overall yield. Also, the time to complete a carbonization cycle is extended, thus increasing costs. The volume of unseasoned wood is also higher than that of dry wood and the packing fraction (stack density) of the kiln is thus marginally reduced when green wood is used. Wood can be dried in the air without any heating cost. About three months of drying is roughly optimum but this varies with climatic conditions and type of wood.

Large wood pieces carbonize slowly since the transfer of heat into the interior of the wood is a relatively slow process. Sawdust, for example, can be flash-carbonized very rapidly but the powdered charcoal produced has low market value. On the other hand, large diameter trunks of dense species may shatter when carbonized, making the charcoal more friable than desired. Studies have shown that charcoal with optimum properties for the iron industry is produced with wood pieces measuring about 25-80 mm across the grain. The length along the grain has little influence (Antal, *et al*.,1990).

Charcoal yield is also affected by the peak temperature, that is, the highest temperature reached during the carbonization process. This temperature largely controls the quality (volatile matter content) and other properties of the charcoal product. With the temperature between 100 and 180ºC, all loosely bound water is evaporated from the wood. In the temperature range 180-270º C gases released containing CO, CO_2 and condensable vapours form pyrolysis oil. Above 270 and 288ºC, the exothermic reaction starts, this can be detected by the spontaneous generation of heat and the increasing temperature of CO and CO_2 gases. The quantity of condensable vapours also increases. At temperatures below 220ºC, cellulose loses weight mainly through the formation of water but at higher temperatures (up to 250ºC), CO_2 and CO are also produced (Antal, *et al*., 1990; 2003).

Once the carbonization process has entered the exothermic phase, no more external heating is required. This condition is sufficient to attain the temperature of 600ºC. The mixture of gas and vapour expelled from a continuous carbonization process remains uniform during the time of the process. The continuous operation of a charring unit depends on the residence time of wood, and for a relatively short time it remains within the hot zone.

4.0 BEST PRACTICES FOR CHARCOAL PRODUCTION USING THE CASAMANCE KILN

4.1 Kiln design and fabrication

The materials for chimney construction include four 210 litre steel drums closed at both ends and a 2-inch mild steel pipe (1 metre long) to collect the condensed tar. Three drums are welded together to form the chimney, and their ends are bent inwards as shown in Figure 1. The angle through which the ends are bent, the diameter and height of the chimney, and the number and size of flue holes are subjects for further research. In this case, the drums used were 0.52 m diameter and 1.0 m high. The angle through which the drum ends were turned was approximately 12°. To the lower drum are welded the fourth drum at 90° to form the flume that is placed in the kiln during the carbonization process, and the tar condensation pipe slightly bent downwards to facilitate tar flow. To the top drum are cut 8 flue holes, equally spaced around the drum circumference.

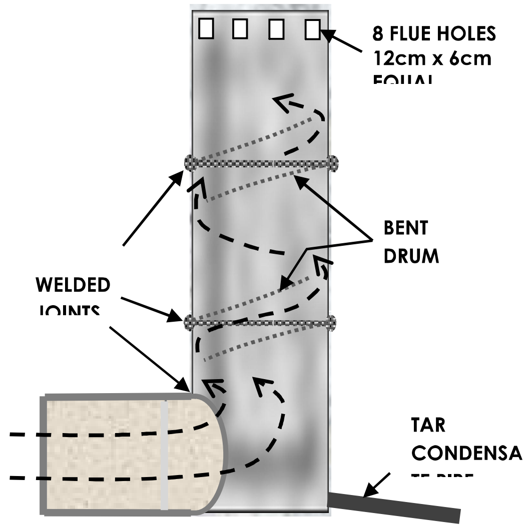

Figure 1: Chimney for Casamance kiln

4.2 Casamance kiln construction

The efficiency of Casamance charcoal kiln depends on how well the base of the kiln is constructed. This plays an important role as it guarantees a degree of airflow in the kiln. The base is constructed radially from the centre outward with two layers of small and medium sized wood. For the second layer, wood is arranged across the first layer. The layers, composing of large billets of 40-50 cm in diameter are arranged close to the centre of the kiln around a pole fixed in the ground. The gaps are always filled with small and medium sized wood, to strengthen the kiln and create a medium for quick heat transfer when the kiln is charged. The last covering layer is composed of mixed sized short pieces of wood arranged around the outline of the base. When this is completed, the kiln is covered with a skirt of soil clumps on the sides and grass or leaves at the top, and then a thin layer of loose soil above the skirt of soil clumps up to the top of the kiln. The chimney is placed at the edge of the kiln. The flume of the chimney must touch the base of the (stacked) wood.

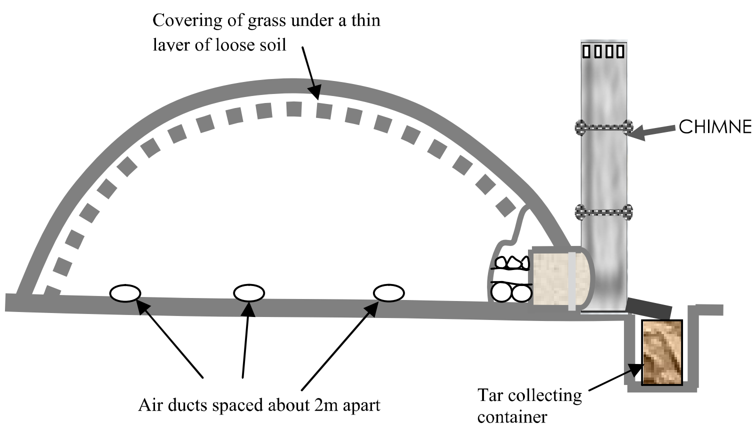

Figure 2: The Casamance kiln

The Casamance mound is based on reversed draught, i.e. air flows in from the bottom of the vent holes and warm gas instead of escaping from the top, flows down and through the chimney which is connected to the base of the mound.

4.3 Carbonization process control and management

Once the fire is started, constant supervision by the attendants is needed until carbonization is completed. The mound is lit in the central hole by throwing in live embers. When the fire has started (15 to 20 minutes) the central hole should be closed. Ventilation holes should be opened every 3 to 4 metres around the base of the mound. A hole should never be made near the chimney as this will only reduce the draught in the rest of the pile. If smoke does not rise out of the chimney, a small fire should be lit in it to make it draw.

As carbonization advances the mound sinks progressively and holes may appear which should be immediately blocked with grass and sand. The chimney should be removed if the side on which it is situated seems to be completely carbonised.

Figure 3: The stacked kiln

Figure 4: The kiln during carbonization

Carbonization is at an end when the smoke starts to diminish and turns blue. From this moment it is the charcoal itself which is burning, hence the necessity to withdraw the chimney and close the mound hermetically. After cooling the mound is opened with the aid of rakes beginning at the base. The opening should be closed after a part of the charcoal has been removed and this procedure should be continued until the operation is completed.

5.0 RESULTS AND DISCUSSION

The results obtained by operating 10 kilns are presented in Table 2. A set of five experiments was performed, with each set comprising of two kilns, a traditional earth mound and the improved Casamance kiln. The two kilns in each set were constructed in the same locality, at the same time and using the same wood species under the same conditions.

Table 2: Kiln efficiency measurements

Kiln Code	Air-dry wt. (kg)	Stack vol. (m^3)	[1]Stack density (kg/m^3)	[2]Moisture cont. (%)	Charcoal wt. (kg)	[3]Oven-dry yield (kg)	Duration of carbonization (days)
CK1	3614	8.3	435.42	31.0	792	28.7	6
TK1	3610	7.9	456.96	31.0	430	15.6	14
CK2	4557	10.5	434.00	28.4	1043	29.4	6
TK2	4565	12.4	368.15	28.4	540	15.2	15
CK3	4896	12.7	385.51	27.2	1174	30.5	7
TK3	4878	12.4	393.39	27.2	621	16.2	16
CK4	5850	14.2	411.97	24.3	1417	30.1	7
TK4	5853	14.0	418.07	24.3	739	15.7	18
CK5	6897	15.6	442.12	18.5	1734	29.8	8
TK5	6888	15.3	450.20	18.5	889	15.3	24

CK = Casamance kiln
TK = Traditional kiln

$^1\text{Stack density} = \frac{\text{airdry wt. of wood}}{\text{stack volume}}$, $^2\text{Moisture Cont. (M.C)\%} = \frac{\text{A - B}}{\text{B}}$; A = airdry wt., B = ovendry wt.

$^3\text{Yield \%} = \frac{\text{wt. of charcoal}}{\text{wt. of charge (ovendry)}}$, $^3\text{Ovendry wt. of charge} = \frac{\text{airdry wt.}}{1 + \text{M.C}}$.

The tree species used in this research are a mixture of *omukoora* (terminaria glaucensi), *omugavu* (albizia corianria), *omurongo* (albizia gummifera), *endagi*/*omurama* (combretum molle), *tokekulu* (phoenix reclanata), *kibere* (acacia spp), *omukara* (combretum brown), among other species.

From Table 2, it can be concluded that the Casamance kiln exhibited a better performance than the traditional earth kiln operated under similar conditions. In a previous study (Nturanabo, 2010), the charcoal produced by the Casamance kiln was found to be of better quality as well. There was remarkable improvement, though, in the performance of the traditional kilns due to improved supervisory skills and application of the best practices learnt during the research project.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The performance of the Casamance kiln in terms of the charcoal yield and duration of carbonization was far better than that of the traditional kiln using the same amount of wood and operating under similar conditions. It has been shown that adoption of the Casamance kiln can save significant amounts of wood, and hence forests cut for charcoal production.

6.2 Recommendations

Further research should be carried out to establish the optimum design of the Casamance kiln, by matching the kiln dimensions and chimney size. In this research, only one chimney was used in all experiments, which could be a deterrent in recommending the best operating practices for the Casamance kilns. It should be noted that for sustainable consumption of the forest resources to be realised, there should be deliberate effort to minimize material and energy losses and improve efficiency at all stages. Thus, wood obtained from sustainably produced biomass is harvested using efficient ways ensuring minimum waste, and then is converted into charcoal using improved and efficient kilns after which proper handling is ensured during packaging, storage and transportation. Finally, the generated charcoal is consumed using improved cookstoves.

7.0 ACKNOWLEDGEMENT

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8.0 REFERENCE

Antal, M.J. and Morten Grønli, (2003) The Art, Science, and Technology of Charcoal Production, *Ind. Eng. Chem. Res.*, pp *42,* 1619-1640.

Antal, M. J.; Mok, W. S. L.; Varhegyi, G.; Szekely, T., (1990) Review of Methods for Improving the Yield of Charcoal from Biomass. *Energy Fuels. pp 4, 221*.

Energy Systems (2009) Vulnerability – Adaptation – Resilience (VAR). Regional Focus: sub-Saharan Africa Uganda,.

FAO (1987) Simple Technologies for Charcoal Making, *FAO Forestry Paper 41, 1987*, Food and Agriculture Organisation of the United Nations, Rome.

Kristofferson, L. A. and Bokalders, V. (1986) Renewable energy technologies: Their applications in developing countries. *Pergamon, Potts Point, Australia*.

MEMD (2007) Renewable Energy Policy for Uganda,. *Ministry of Energy and Mineral Development, Kampala, Uganda*.

Nturanabo, F. and Tumuhimbise, J. (2010) Improved charcoal production methods using the casamance kiln in Uganda. *Proceedings of the Forest Bioenergy 2010 Conference, Tampere & Jämsä, Finland – August – September 2010.*

Raveendran, K.; Ganesh, A.; Khilar, K. C. (1996) Pyrolysis characteristics of biomass and biomass components. *Fuel*, pp *75*, 987.