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Effect of Wood Moisture Content and Log Diameter on Conversion Efficiency of a Drum Kiln

(Effect of moisture content and log diameter)

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ABSTRACT

In Zambia wood fuel, as a forest resource currently accounts for 80% of the country's total energy consumption at household level. About 60.9% of households use firewood for cooking and 24.3% use charcoal while only 13.8% use electricity. Further in rural areas, 87.7% use wood for cooking, 9.5% use charcoal and only 1.5% used electricity. Traditional earth charcoal kilns are the dominant method used in charcoal production, they incur minimal construction costs for rural communities, but have low conversion efficiencies, ranging from 6 to 12%.This causes high annual rate of deforestation due to wood harvesting. For every ton of charcoal produced using traditional kiln depletes 0.1 hectares of woodlands. Zambia has 300 000 hectares per annum rate of deforestation that is increasing at rate of 4% per annum. This research was about determining the effect of moisture content and log diameter on the conversion efficiency of drum type charcoal making kilns by comparative studies in the field. The drum kiln is intended for use at the household level in peri-urban and rural areas. The log diameters used in the experimentation ranged from 0.04 m to 0.16 m on an average scale. The moisture content of the wood was determined by oven dry method (ASTM-D-4442) which yielded moisture content ranges of 26.92 wt. %, 9.42 wt. %, 8.63 wt. % and 9.06 wt. % respectively.

The arrangement of the wood inside the kiln was cross wise and longitudinal loading. Tests were carried out for both uninsulated drum kiln and an earth insulated drum kiln in order to observe the effect of earth insulation on the retention of the heat of carbonization. It was

There is need for a kiln which can help improve the conversion efficiency like the drum charcoal kiln adopted here for use at low income household level. To achieve this, one needs to determine the effect of some of the most important factors affecting conversion efficiency in any carbonising kiln and simplify charcoal production at low income household level.

It was observed that the lower wood moisture content and larger diameter wood logs resulted in higher conversion efficiency. This means that carbonization in the small logs easily turns into combustion process especially with an insulated drum kiln which retains heat inside thus reducing the conversion efficiency.

It was observed that the average time taken for complete carbonization of smaller diameter logs (0.04-0.1 m) was 8 hours and 12 hours for larger diameter logs (0.1-0.16 m). Heat transfer in larger logs was found to be slower because of the larger effective radius for heat transfer. This slow process of heat transfer aids in complete carbonization without leading to combustion. The logs shrunk very little with time hence maintaining their shapes. The lowest conversion efficiency value obtained was 11.1 percent for the smaller log diameters and the highest conversion efficiency was 29.66 percent for the larger diameter logs with lower moisture content. The uninsulated drum kiln proved difficult in respect of the carbonisation to take effect as the process could not continue due to loss of heat through the uninsulated drum metal wall. Thus the drum kiln has potential for efficient charcoal production at peri-urban and rural household levels because it can mitigate the energy deficit at the same time helping fight deforestation.

INTRODUCTION

Charcoal is an important energy source in Zambia, it ranks second to firewood in terms of primary energy supply [4]. It is the solid residue remaining when wood is "carbonised" or "pyrolysed" under controlled conditions in a closed space such as a charcoal kiln where control is exercised over the entry of air during the carbonisation process to form charcoal [5]. In Zambia, the most commonly used method of making charcoal is the traditional earth kiln. In this research, however, the Drum kiln method of making charcoal was adopted because the traditional earth charcoal making kilns commonly used in Zambia have low conversion efficiencies ranging from 6 to 12 %. This low conversion efficiency has led to the high annual average rate of deforestation which stands between 250,000 and 300,000 ha of forest area per annum [6]. This calls for improved household level charcoal making kilns

EXPERIMENTAL METHOD

A study of the existing charcoal making kilns was carried out in order to identify their problems and limitations. The experiments were design and set up using the engineering statistical methods [7-8]. Logs were cut to appropriate lengths and their diameters and weights measured using balance scales, strings and measuring tape. The moisture content was determined using [9].

The wood species used was the Mutondo (Julbernardia Paniculata) (Figure 1) which has a. high density (710 kg/m^3) meaning it is able to maintain its solidity by shrinking by a small margin after carbonisation as compared to softwood species [3].

Figure 1. Mutondo (Julbernardia Paniculata leaf)

The logs were transported from Mwekera forest to the experimentation site at the Copperbelt University in Kitwe where they were sorted out according to diameter range as seen in Figure 2.

Figure 2. Sorted logs of various diameters``

The oven dry method of moisture content determination as described under [7] was applied. Samples of the sorted logs were taken to the Chemical engineering laboratory where they were each weighed for mass using an electronic beam balance and were left in the closed oven for an initial period of6 hours at 103 ºC after which their masses were taken again to determine loss of moisture. The samples were taken back into the oven with intervals of 2 hours and checking the masses of the specimens at each interval until each specimen stopped showing signs of changing weight thus being oven dry completely. This was repeated for days and to keep the samples from absorbing atmospheric moisture overnight, samples were kept inside a desiccator with bags of silica to absorb moisture.

The logs sorted according to diameters and moisture content were charged into the drum kilns and then carbonised accordingly. Once the carbonisation was completed, the charcoal was collected, cooled and weighted and labelled according to condition of charged in raw wood logs. The **Figure 3 and 4**. depict the experimental setup.

Figure 3. Logs loaded longitudinally LHS and crosswise RHS in drum Kilns

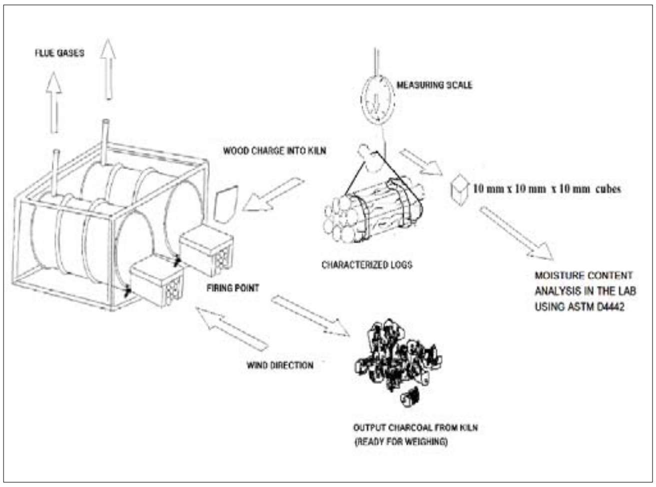

Figure.4. Schematic of the experimental setup.

EXPERIMENTAL CONDITIONS

Table 1. Atmospheric conditions on sight

Ambient Temperature	25^o C
Pressure	100.91 kPa.
Dew point	4^o C
Wind direction	SE 15 km/hr.
Gusts of wind	E at 23 km/hr.
Humidity	26%
Cloud cover	6 %

(**Source**: AccuWeather.com)

The parameters under consideration were;

1. Average ranges of Log diameters
2. Average moisture content of the wood
3. Prevailing wind direction

4. Log arrangement and kiln loading
5. Thickness of earth insulation layer
6. Kiln management

WOOD CARBORNISATION IN THE DRUM KILNS

After initial firing, a time period of 30 minutes was enough to start carbonisation and at this point the kilns were sealed off completely. A layer of loose earth insulation was used to retain the heat of carbonization. The smoke colour was observed during the whole carbonisation process. In the initial stages, the smoke was thick and white, **Figure 5**, this is the stage when moisture is being driven off and the condensable tars being given off. This went on for hours and once the wood was bone-dry, carbonisation started to occur slowly and it occurred best when there was enough space underneath the wood for air circulation, this is the reason why wire gauze was used.

Subsequent observations of the colour of the smoke were made. The smoke colour was changing accordingly as the volatile and non-volatile gases were being driven off the carbonising wood in the drum kiln.

Figure 5. Wood drying stage of carbonisation

The charcoal harvested was sorted out according to drum labelling and after cooling it was packed in 25 kg and 10 kg bags for weighing so that values of kiln efficiency could be calculated.

Some formulae were used for moisture content calculation and kiln conversion efficiency.
Conversion efficiency (E_{kc}) is determined by Equations (1) and (2) on dry basis:

$$\text{Ekc}(\%) = \frac{mass\ of\ charcoal}{mass\ of\ dry\ wood} 100\% \qquad (1)$$

Wood weight percent moisture content, M (Wt.%) is given by the formula below as per ASTM-D4442:

$$\text{M}(wt\ \%) = \frac{\text{A}-\text{B}}{\text{B}} \times 100\% \qquad (2)$$

Where
A is the initial weight of the cubed specimen in grams (g)
B is the Oven dry weight of the cubed specimen (g

PROCESSING OF RESULTS

The **Tables 2 – 5** show the range of diameters and their conversion efficiencies at a particular moisture content as recorded from the experiments. The logs loading arrangements in the drum kilns are as shown in **Figure 3**: longitudinally (logs loaded along the drum length) in the left hand side drum and crosswise (some logs loaded along drum length and next layer of logs loaded at right angle to this layer along drum diameter) in the right hand side drum.

Table 2. Log diameter range and Conversion efficiency at 26.92 wt. (%) average moisture content

Arrangement	Crosswise loaded kiln		Longitudinal loaded kiln	
Average Log Diameter Range (M)	0.04-0.06	0.06-0.1	0.04-0.06	0.06-0.1
Conversion Efficiency (%)	15.90	18.52	11.11	12.5

Table 3. Log diameter range and Conversion efficiency at 9.42 wt. (%) average moisture content

Arrangement	Crosswise loaded kiln		
Average Log Diameter Range (M)	0.04-0.06	0.06-0.1	0.1-0.16
Conversion Efficiency (%)	26.67	20.83	24.54

Table 4. Log diameter range and Conversion efficiency at 8.63 wt. (%) average moisture content

Arrangement	Crosswise loaded kiln		
Average Log Diameter Range (M)	0.04-0.06	0.06-0.1	0.1-0.16
Conversion Efficiency (%)	20.11	22.29	24.69

Table 5. Log diameter range and Conversion efficiency at 9.06 wt. (%) average moisture content

Arrangement	Crosswise loaded kiln		
Average Log Diameter Range (M)	0.04-0.06	0.06-0.1	0.1-0.16
Conversion Efficiency (%)	28.66	27.87	29.66

TRENDS AND RESULTS

Effect of log diameter on kiln conversion efficiency

The **Figures 6 -9** shows the experimental results for conversion efficiencies for the various ranges of log diameters at various wood moisture contents.

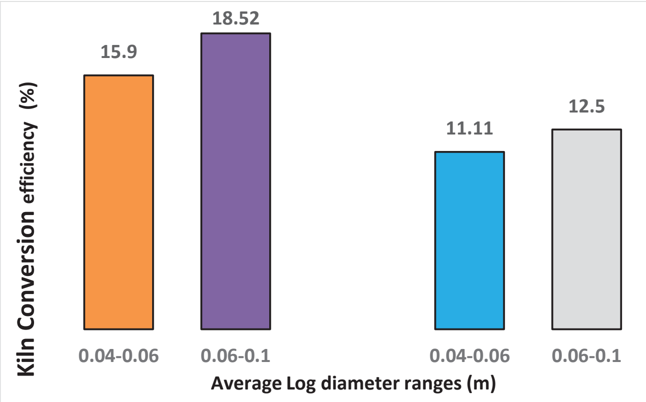

Figure 6. Average log diameter range vs. Conversion efficiency at 26.92 wt. (%) average moisture content (Cross & Longitudinal Loading).

Figure 6's last two bars show conversion efficiencies of below 13% for both ranges of average log diameters for longitudinal type of loading. Several trials were carried out for the longitudinal type of loading and the conversion efficiency was consistently below 13% which is rather low. Hence presented here are results for cross loading arrangements only which were giving conversion efficiencies above 12%.

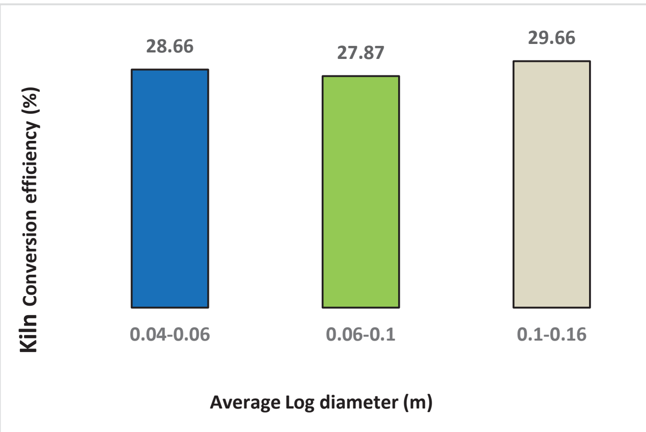

Figure 7. Average log diameter range vs. Conversion efficiency at 9.42 wt. (%) average moisture content (Cross-Loading).

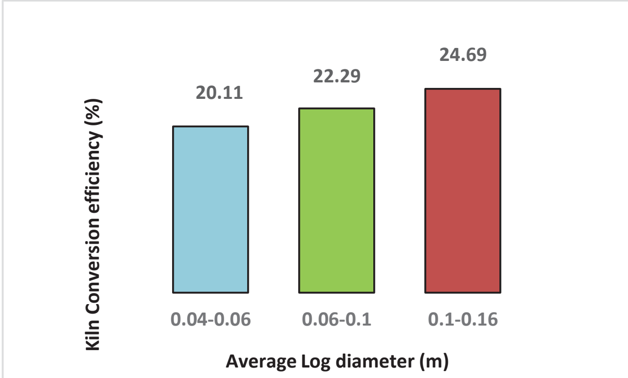

Figure 8. Average log diameter range vs. Conversion efficiency at 8.63 wt. (%) average moisture content (Cross-Loading).

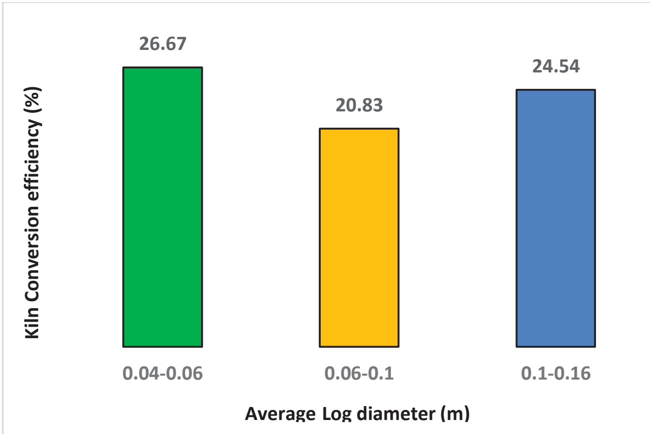

Figure 9. Average log diameter range vs. Conversion efficiency at 9.06 wt. (%) average moisture content (Cross-Loading).

From the observation of the bar charts, the conversion efficiency increases with an increase in the log diameter reason being that from the heat transfer basis taking a cylindrical model to represent the log, for small logs the heat transfer happens in a shorter time as compared to a larger log.

This means that carbonization in the small logs is quicker than in the larger logs, the heat inside the kiln however, causes the charcoal formed to start combusting thereby reducing the efficiency as observed at carbonization time of eight hours. On the other hand, heat transfer in larger logs is slower because of the larger effective radius, this slow process aids for proper slow carbonization as the log shrinks very little with time hence sustains its shape.

Effect of the wood moisture content on Kiln conversion efficiency

From the experimental results, **Figure 10** shows the variation of the conversion efficiency with reduction of wood moisture content. This is still a case for a cross-loaded drum type charcoal making kiln. It was observed that at certain moisture contents the conversion efficiency was lower or higher than expected due to level of kiln management and the fact that the wood sample batch could have absorbed moisture from the atmosphere at the experiment site.

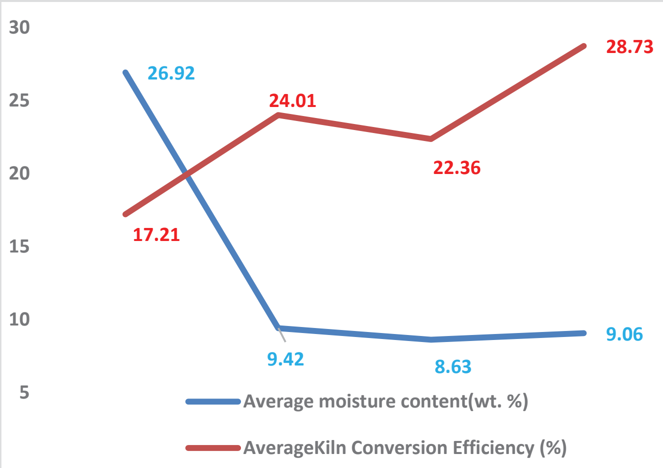

Figure. 10. Variation of Average moisture content with. Conversion efficiency

The graph (**Figure 10**) obtained from the data shows that the kiln conversion efficiency increases as the wood moisture content reduces. This is so because when wood is fresh it requires a larger quantity of dry wood for kiln firing until such a point that the moisture has been driven out of the wood so that there is no more need for external heating, this same wood should have been converted to charcoal, instead it is used to drive moisture out. But as the moisture content reduces due to open air drying, the conversion efficiency increases because a lesser amount of wood is needed to drive out moisture.

OTHER MAJOR FACTORS OF INFLUENCE

Prevailing wind direction

The drum kiln setup was oriented in such a way that the kiln firing point was along the wind direction. This was in order to aid for adequate supply of oxygen to aid in the initial combustion during kiln firing and in the driving out of the gaseous products of the carbonization process. Research conducted by E. Luwaya [3] shows that orienting the firing point against the wind direction reduces kiln conversion efficiency.

Log arrangement and kiln loading

Several trials were done on cross-wise and longitudinal wood arrangement methods and the longitudinal loading gave very low conversion efficiencies below 13% and in a number of trials the wood charge arranged longitudinally did not carbonize. This was because close stacking without spaces between the longs starved the kiln off oxygen in the initial stages of carbonization.

Kiln loading also played a role in that if the kiln is filled to capacity, there was little space for air circulation. Several times it was observed that when the kiln was loaded from the bottom up, as the ashes were forming, they blocked air circulation, this in turn put out the kiln, after that observation, it was decided to put two steel bars near the entrance and at the farthest point inside the kiln and putting a wire gauze on top where the wood was stacked, the space created underneath the wood aided the circulation of air inside the kiln thereby sustaining it through carbonization without going off.

Thickness of earth insulation layer

During the initial stages of experimentation the drums were not insulated and the results obtained were mostly ashes. This was so because the much needed heat of carbonization was lost to the surrounding due natural convection from the drum surface which lead to reduction in the conversion efficiency. a 6.5 cm of loose earth insulation layer was plastered around the drum kilns which helped retain most of the heat of carbonization but the heat was too much and the charcoal ended up spontaneously combusting thereby reducing the conversion efficiency. The insulation thickness was reduced from 6.5 cm to 3 cm which corresponded to good range of efficiencies as compared to the latter.

Kiln Management

Kiln management was the most challenging part of the whole project, at times the kilns used to go off completely in absence of supervision which meant starting all over again. This entailed monitoring the kilns at awkward hours of the night (02:00 am) depending on the time of firing. Knowing exactly what time to open the kilns was critical because opening it too early interrupted carbonization living some of the logs uncarbonised or partially carbonized. On the other hand, opening the kiln late, yielded ashes as the charcoal formed combusted. The average time for the carbonization for the smaller logs (0.04-0.06 m) was eight hours and that for the bigger logs (0.06-0.16 m) was eleven hours. [1-2]

It was challenging to observe the colour of the smoke for sessions that went into the night because of low visibility and smoke colour was key to understanding at which stage of carbonization the kilns had reached. Blue acrid smoke meant that carbonization was complete and combustion had started instead while thick white and yellow smoke signalled that the condensable tars were being driven off. Upon firing, the kiln should be left open for half an hour after which it has to be closed and sealed off of any air entry point with clay to prevent air entry which could cause combustion of the logs and only leaving the chimney stacks open for flue gasses.

CONCLUSIONS

The conversion efficiency of a drum kiln increases with an increase in Log diameter due to the ability of hardwoods to maintain their solidity with little change when undergoing carbonization and this is so because of their relatively high densities which facilitates for slower rates of carbonization.

The lowest efficiency recorded was 15.9 % at 26.92 wt.% average moisture content and the highest being 29.66 % at 9.06 wt.% showing that conversion efficiency of drum kiln increases with a decrease in the moisture content of the

Lack of insulation on the drum kiln, causes a lot of heat energy of carbonization to be lost to the surrounding leading to low kiln conversion efficiencies due to most logs not being carbonized.

The experimentation has shown that the most suitable arrangement of the logs for optimum conversion efficiency is cross loading.

Kiln management is critical and ought to be observed. Upon firing. The level of kiln management was the one major factor causing variation in the conversion efficiency values.

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