Making Charcoal Production in Malawi Sustainable

Relatively low-cost masonry "retorts" combined with affordable high efficiency charcoal stoves will decrease the fuelwood usage with 80%.

From an overall energy point of view the difference between charcoal and wood turned out to be negligible.

Industrial retorts for carbonization of all types of biomass

Giel de Pooter, Feb. 2016
"Promotion of Cleaner Cooking in Malawi"
Version 4

Making Charcoal Production in Malawi Sustainable

(an overview of the available literature)

Summary

The major cause of deforestation in almost all Sub-Saharan Africa countries is the increasing use of wood for household cooking both by using wood-cookstoves and charcoal-cookstoves. Especially the use of charcoal is seen as the major culprit of the disappearance of huge areas of woodlands. However, it has been demonstrated in various studies that after modernisation and professionalization across the entire value chain the charcoal will become a sustainable product. After formalizing the business for a large group of people jobs will be created, while revenues for the government will also increase significantly.

Combination of the following two interventions will save 75 to 80 % of the presently used wood in the charcoal consumption:

- *Relatively low-cost masonry "retorts" will be one of the approaches to reach a 35-40 % efficiency of the charcoal production (versus 10-15 % obtained in the traditionally earth-mount kiln). Furthermore this retort system reduces the emission of harmful volatiles into the atmosphere with about 75 %. The predicted savings of improved kilns is estimated to be 50 %, which corresponds roughly to about 12,000 ha woodland annually [estimated from the data given in ref. 1]*
- *The distribution of affordable high efficiency cookstoves which decrease the charcoal usage with 60 % has already been successfully started by our foundation.*

Both the Envirofit cookstoves (charcoal and wood), which are discussed in this document have about equal thermal efficiencies. If charcoal is produced using the traditional kiln at an efficiency of 15 % (15 kg/100 kg wood) about 3.3 kg wood is needed for a charcoal stove compared to 1 kg wood to a woodstove. An improved kiln (assume 35 % efficiency) reduces this figure to 1.4 kg. The cooking habit of many women lowers the theoretical efficiency of woodstoves significantly which makes the difference between charcoal and wood negligible.

A comprehensive overview of the consulted literature has been given at the end of this document while a number brochures describing the issue in great detail are recommended for the more interested reader.

Key findings

Estimated woodfuel demand in Malawi is 13 million tonnes annually (65/70 % firewood and 30/35 % charcoal).

From an energy viewpoint the difference between wood and charcoal will become negligible after the following interventions.

- Improved charcoal stove uses 60 % less charcoal.
- Optimized charcoal production results into efficiency improvement from 15 % to 35 %

  The results of these combined effects are:
  - A wood saving of about 80 %
  - Much healthier environment for both charcoal producers and cooks
  - A substantial decrease in the emission of greenhouse gasses
  - Alternative feedstocks like bamboo and agricultural waste (e.g. cotton stalks and maize cobs) can be converted into valuable fuel.
  - Optimized charcoal production will also generate valuable by-products like woodvinegar

Advantages of charcoal versus wood:

- Higher energy
- Cleaner cooking
- Lower transport and storage costs
- No preparation like cutting and drying
- No biological decay during storage

1. Fuelwood in Malawi (Charcoal + direct use)

About 95 % of the rural population uses firewood as their only energy source. In the urban regions and in the peri-urban people are using charcoal as their primary energy source for cooking. Only about 50 % of the urban population is connected to the grid but due to the increasing costs of the electricity they prefer cooking on their charcoal stove [1].
The preference of charcoal above wood is mainly socio-cultural determined. Other differences between these two energy sources will be outlined later.
Based upon a number of publications the total demand for wood (both for fuelwood and charcoal) is estimated to be 2 kg [14] per person per day (thus presently the Malawi population uses 13 million metric tons wood annually). Apart from household cooking, firewood is also been consumed in the tobacco industry and in the production of bricks.

2. Wood consumption in the villages

In rural regions firewood is mainly collected by women and children in the neighbourhood of the villages. As long as they find sufficient dead wood and twigs the burden upon the woodland is relatively low. However, it should be noted that every year they have to walk a longer distance and thus more and more stem wood will be used as well. Recently, through my foundation improved woodstoves have become available in the country. It has been proven that these modern stoves minimize the use of fuelwood with about 60 % (see section 9).The amount of noxious products e.g. Particulate Matter (P.M), smoke, Carbon-monoxide (CO) is lowered with the same percentage. Users claim that even when using maize stalks the smoke level is acceptable. Including Tax (about 60 %) the cost prize of these stoves is about KM 16, 000 (based upon a kwacha to the dollar rate of 600). When the prize of fuel wood is taken into account the payback period is less than 6 months (guaranteed lifetime of the stove is 3 years). However, because people are having their fuelwood free of charge there is at the moment no economic incentive for most of the users.
Consumer price is significantly affected by the tax-level (60 %). Tax exemption combined with e.g. the Villages Saving and Loan program will make these stoves affordable for a significant part of the population in the rural villages.

3. Charcoal consumption in the urban and peri-urban

The rural poor have no other source of income and the urban poor have no other source of energy.

A study published in 2007 by Patrick Kambewa at all. [1] states that the charcoal business is one of the largest in Malawi; if the product was exported, the annual foreign exchange income to the country would fall somewhere between that of tea (Malawi’s second largest export after tobacco) and sugar (3rd-largest in 2006). The economic value in 2007 was estimated to be 41.3 million USD. Taken into account the growth of the population, the increased degree of urbanisation and the severe devaluation of the kwacha I estimate that this figure will have increased in 2016 to a value between 300 and 500 million USD.

A few facts from this report [1] (2006-2007 figures):

- About 100,000 people owe their livelihoods on charcoal.
- Annual usage of charcoal in the major urban regions in 2007 was 230,000 metric tons, which requires 1,400,000 m3 wood (15,000 ha woodland annually; which was at that time about one-third of the annual deforestation). In view of the overall population growth the current figures will be appr. as follows: 325,000 metric tonnes charcoal; 2 million tonnes wood (21,000 ha woodland for charcoal production). In a more recent article the firewood equivalent is estimated between 3.5 and 4.5 million tonnes. [*]
- The annual expenditure on charcoal in the urban regions was nearly 4 times the expenditure on electricity.
- Traditional earth kilns are the standard which means an efficient conversion of not more than 15 %.

Cost structure of the charcoal value chain:

Producer: 21 %, Packer: 6 %, Transport: 25 %, Market fee: 3 %, Private taxes: 12 % and Retailer: 33 % (see page 8).
Mainly all the wood originates from clear cutting (slash and burn) and selective cutting and thus essentially free of charge and consequently the charcoal is estimated to be underprized by about 20-50 % [4].

Charcoal producers can be categorized according to their level of production:

- 7000 small-scale incidental producers (average less than 30 bags per month) produce together nearly 40 % of the total charcoal production.
- The medium-scale producers (2000) with an average of 30 -100 bags a month produce about 25 %.
- There were in 2007 only about 350 large-scale producers identified.

As long as none of them has to pay for their feedstock ("free collection of wood") there will be no economic drive to make investments for the necessary improvement of the efficiency conversion from about 15 % to 35%. The predicted savings of this development is estimated to be about 50 %, which corresponds to roughly about 12,000 ha woodland annually (estimated using data presented in ref. 1).

The result of this study [ref. 1] shows that at in 2007 about 90 % of the charcoal is used by the four largest urban centres (Blantyre, Lilongwe, Mzuzu and Zomba).
Thus charcoal is a vital energy source for the urban poor. Low-income households have a higher per capita charcoal consumption, while three-quarters of their total household energy expenditure is spent on charcoal or wood.
Also middle income groups cook with charcoal on a daily basis. Consumers who have access to electricity and LPG use charcoal during the frequent power outages and LPG shortages while the price increase of these fuels play a role as well.

*https://cdm.unfccc.int/filestorage/l/1/S32CRUG0WBNZQ16H85EVXAO9DKJTF7.pdf/CQCapital_Malawi%20NRB_C4ES_28%20May_31%20jan.pdf?t=a0F8bzJobGZ2fDA7vwmIkUgN5mH6OHG4WuGA

In the absence of any genuinely viable alternatives that can operate at commercial scales – despite a variety of interesting hobby-level options supported over the years, charcoal will continue to be produced and consumed in Malawi for many more years.

The questions are quite simple: "How to utilize the available charcoal more effectively" and "How do we want to produce this product to meet this market demand in a better manner?"

4. Formalization and modernization of the entire charcoal value chain

Most of the recent publications emphasize that a sustainable improvement of the charcoal business can only be achieved applying a holistic approach [4,5]. In other words modernization of the charcoal sector is needed across the entire value chain. Isolated interventions (reforestation, sustainable forest management, distribution of improved stoves, regulating of trade, etc.) fail to exploit adequately possible synergies that would, if combined, make them sustainable.

Only a few aspects of the value chain can be briefly addressed in this document.

a. Sustainable forest management fall outside the scope of this summary
b. Regulating the market by a taxation system based upon the principle that sustainable produced charcoal is taxed at lower rate than all other charcoal. In the literature mentioned detailed recommendations have been formulated [4,5,11]. The taxes should favour the implementation of efficient charcoal production techniques and the maintenance/regeneration of tree cover.
   Another aspect is that jobs will disappear; a lot of small producers, transporters and traders will lose their job. Because the transition will happen gradually new jobs will be generated. The improved charcoal stove mentioned in section 8 will have to be assembled locally which will give good jobs to a number of people. Furthermore people need to be enabled in trading these stoves.
c. Improved charcoal production procedures (see section 5)
d. Dissemination of improved cookstoves (see section 7)

5. Optimization of the efficiency of the charcoal production using improved kilns.

The reported efficiency of the traditional earth kiln is about 10-15 %. According to a number of publications fine-tuning by experienced operators having knowledge about the carbonization process (see appendix) could result into a somewhat higher efficiency (the definition of the efficiency is outlined in the appendix) .
The implementation of relatively low-cost masonry "retorts" might be one of the approaches to reach a 35-40 % efficiency. Compared to the traditionally earth-mount kiln this retort system reduces the emission of harmful volatiles into the atmosphere with about 75 % [16]. The production of wood vinegar during the first phase of the carbonisation process is also possible. Wood vinegar has useful applications in the traditional agriculture [9] (see appendix).

Investment costs for improved kilns (metal chimneys etc.) do not pay off as long as wood remains a free resource. Despite training support, charcoal burners eventually abandon the improved technology. This is the main reason why the improved and superiorly efficient Casamance kiln has been disseminated since 20 years throughout Africa without success.

The efficiency of the charcoal production is strongly related to the level of the emission of toxic gasses. An improved efficiency will result into a considerable lowering of these products.
Relatively high amounts of methane and other hydrocarbons are emitted due to inefficient carbonization. Worth mentioning is that these chemicals have about a factor of 20 higher global warming potential than CO_2 [http://www3.epa.gov/climatechange/ghgemissions/gases/ch4.html].
In general to achieve higher conversion efficiencies and improved environmental performance the implementation of chimneys and the recovery of tar, wood vinegar and methane is worth investigation.

A large number of improved kilns from simple to complex have been described in the literature [3,6,10]; only a few can be mentioned here.

a. *Casamance-Kiln*

The construction follows an elaborate pattern of laying wood pieces putting the larger ones at the centre, standing the wood upright and allowing for air flow within the lower levels of the stack. The wood is covered fully with leaves and soil. Air inlets and a chimney are placed at the bottom of the kiln. Advantages and challenges: This technology improves on control of the carbonization process and achieves better recoveries. The kiln may not be appropriate for large scale charcoal production [10,11,17].

b. *Half Orange Brick Kiln*

Half Orange kilns can be constructed for medium or large scale production depending on objectives. This kiln consists of a chamber for carbonizing the wood, a firing hole at the top, an entrance door and a number of inlets and ports (capacities up to 19 m3 have been reported) [15]

c. *Adam retort:*

The cheapest semi-industrial kiln having a proven efficiency of about 35 %. An investment of about 1000 USD is needed to build this carbonization unit. The noxious emission is decreased by 70 %; the production cycle included the cooling down step takes only about 24 hours while the production in the earth mound kiln takes 3 – 15 days. In each production cycle about 300-375 kg high quality charcoal can be obtained. Collection of wood vinegar as valuable by-product is also possible [10,11,16].

d. More sophisticated units

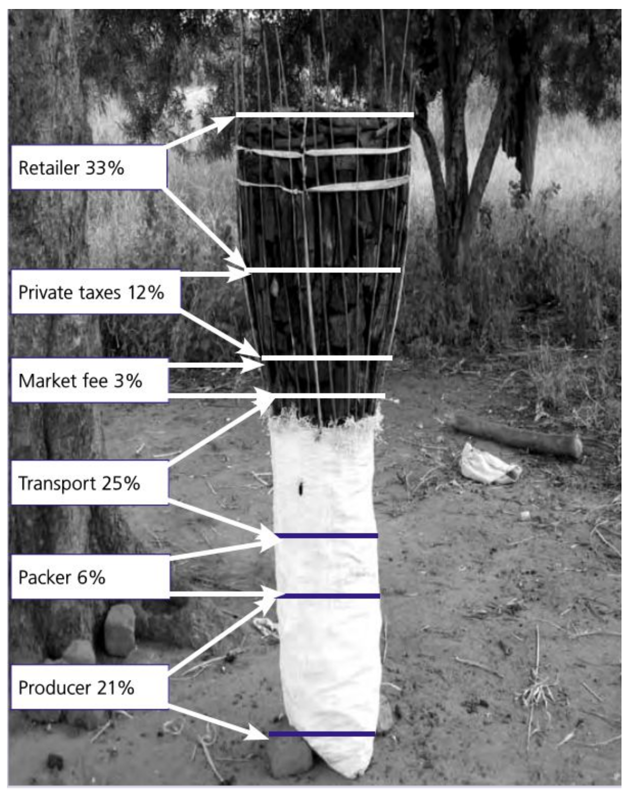
-We should also consider a continues carbonization system in which light biomass like coffee hulls, rice husks, other shredded biomass and wood chips can be carbonized (20,000 USD).
-Advanced industrial retorts might be a step too far at this moment (investment various from 200,000 to 1 million USD) [17]

6. Efficient Kilns constructed in Mwanza and Neno Districts

Recently the Malawi Government has realized that charcoal will still remain one of the major sources of cooking energy in urban and peri-urban areas. Based upon this fact, the Government issued the first ever licence for sustainable charcoal production to a local company. Related to this the Department of Energy Affairs has constructed efficient charcoal production kilns in Mwanza and Neno Districts. Three types of kilns were constructed, Adams Retort, Casamance and Half Orange(personal communication).

Casamanance Kiln

Cost structure in Blantyre (2007) [1]



7. Reduction of charcoal end use

Traditional charcoal stoves use about the same amount of energy as the three-stone wood fire to complete a task (not counting the energy-lost in making the charcoal) and emit up to two times more carbon monoxide. And thus the dissemination of high efficient environmentally friendly charcoal stoves using 60-65% less charcoal has been started recently by my foundation in various towns in Malawi.

Available improved charcoal cookstoves:

Performance

CH-5200:

More than 50% fuel reduction over a typical or traditional type stove! And accommodating large, family-size, pots used in much of the world.

Econochar:

The Econochar is the most cost efficient clean charcoal stove. The stove cooks quickly and efficiently for large families on a small budget. With a support bar that can safely accommodate large cooking pots (onto 13 l pots) and an ash drawer for easy lighting and cleaning the Econochar is a stress free charcoal cooking solution for urban and peri-urban.

Performance improvement versus traditionally Jiko "coalpot" (charcoal)

	Thermal efficiency % improvement	Charcoal % reduction	CO % reduction	Estimated consumer prices including TAX
CH 5200 charcoal	241 %	58 %	49 %	35,000
Econochar charcoal	233 %	57 %	70 %	20,000

Recent interviews with various users in Malawi support these laboratory data ("*1 bag charcoal instead of 3 bags").*

Return over investment of the Econochar (payback period)

An average household in the urban region uses for their daily meals about 3 kg of charcoal which costs about 300 MK (another source mentioned 4-5 kg per day at MK 70 per kg). A simple calculation shows that even the highest investment for a CH-5200 family-sized charcoal stove is earned back in 4.5 months.

Available woodstove

For the sake of completeness the available woodstoves have been mentioned here as well

Household stoves	Wood* % reduction	CO* % reduction	PM* % reduction
M-5000 wood (35,000 MK)	74 %	79 %	70 %
Econofire wood (18,000 MK)	68 %	77 %	47 %

*Performance improvement versus 3-stones Open fire.

8. Comparing wood and charcoal after optimization.

From an energy viewpoint, which is better: wood or charcoal? Each has its own proponents: the supporters of wood claim that charcoal-making wastes a lot of energy. Charcoal advocates say that this overlooks the fact that charcoal has a higher energy yield than wood and lower transport costs.

Both the Envirofit cookstoves (charcoal and wood) which are shown in this document have about equal thermal efficiencies. If charcoal is produced using the traditional kiln at an efficiency of 15 % (15 kg/100 kg wood) about 3.3 kg wood is needed for a charcoal stove compared to 1 kg wood to a woodstove.
An improved carbonization unit (assume 35 % efficiency) reduces this figure to 1.4 kg.
** Taken into account the difference in caloric value between wood and charcoal (see appendix).*

Another item which should be considered when comparing wood and charcoal is the theoretical versus the practical efficiency.

> In case of woodstoves, there is a significant difference between the thermal efficiency measured under optimized circumstances and the day to day practice. Nearly all woodstoves as well as the open fires need continuous attention during the cooking process. To prevent flames at the outside of the stove, which cause loss of energy and damage of the stove, the wood sticks have to be pushed into the fire continuously. This is common practice during e.g. the preparation of nsima however, when boiling beans (2 hours) people forget to pay attention. The consequence is that a significant part of the wood is lost. This does not play a role when using a charcoal stove. Thus eventually, the direct burning of wood might need more wood than consumed in the charcoal route.

These observations are in line with the GIZ report [12]. According to this report the wood equivalent used for an improved woodstove is 6.5 kg; for an improved charcoal stove combined with a retort kiln a wood equivalent of 7.3 kg is needed (1.12 kg/kg).

Some advantages of charcoal versus wood:

- Higher energy
- Cleaner cooking
- Lower transport costs
- No preparation like cutting and drying
- No biological decay during storage

More aspects have been described in the appendix of this report.

9. Health implications for the user

Based upon a brief literature review I come to the following preliminary findings:

1. Particular matter $PM_{2.5}$

   Exposure-Response relationship for child pneumonia [a]
   Relative Risk factor

3-Stone Fire:	2.9
Econofire woodstove:	2.5
Econochar charcoal stove:	<1.0

Switching from wood to charcoal results in a giant step forward in the prevention of child pneumonia.

2. Carbon monoxide (CO)

   For the second noxious component, carbon monoxide (CO) the gain of using the charcoal stove is less evident, thus far in only one article [b] the relation between the diagnosed pneumonia rate (children under 5) could be established. The uncertainty in the data however is +/- 18 % and thus a more elaborated literature study will be needed.

   Relative CO emission [c]

3-Stone Fire:	16.0	pneumonia rate: 23 (20-28)
Econofire woodstove:	5.2	pneumonia rate: 14 (11-17)
Traditional charcoal stove:	35.9	pneumonia rate: 28 (26-38)
Econochar charcoal stove:	17.9	pneumonia rate: 25 (22-30)

A significant improvement of the Econochar compared the traditional charcoal stove. But these data also show that compared to wood fire even one of the best charcoal stoves shows about the same CO emission.

References
a. http://apps.who.int/iris/bitstream/10665/141496/1/9789241548885_eng.pdf?ua=1
b. http://www.capstudy.org/documents/CAPS_Protocol_v2_3_061213_Open_Access_Website.pdf
c. Personal communication (Envirofit)

10. Charcoal production from alternative feedstock

Only a brief summary has been given in this document; more detailed information about all the aspects of this subject can be found in references 6,7,8.

Feedstock

The feedstock can be subdivided in the following classes which each having their specific supply chain. For each of these products the collection of the feedstock and the transport to kilns has to be closely studied and optimized.
One has also to take into account that the end-product of the carbonization process of most alternative feedstocks will need to be converted into briquettes (after sizing). All of these additional steps in the supply chain will bring additional challenges.

a) Energy Crops
b) Harvest residues
c) Processing residues
d) Charcoal dust

a. Main interest at the moment is focussed on Bamboo because it grows fast. After 4 years the plant is fully grown and can be harvested. However, in general the faster the tree grows the lower the charcoal quality. All types of kilns seem to be applicable for turning the bamboo culms into charcoal. However, carbonized bamboo culms are not commonly used as fuel as such. Due to its shape the bamboo charcoal will burn fast, whereas charcoal is typically appreciated for its slow and long burning. And thus further conversion into charcoal briquettes is required [6,7].

   In some African countries eucalyptus is being promoted as a fast growing and profitable source of biomass for charcoal and material for construction work. However, it has been stated that the eucalyptus absorbs large quantities of nutrition from the earth and can bring a disaster to the local ecotypes. In general one have to avoid monocultures which can be accompanied by plant diseases [14].

b. Harvest residues
   One remark in advance: Only the harvest residues which are either removed from the field or burned away by the farmers can be used. There is a good reason for leaving a certain portion of waste in the fields. Biomass turns over needed nutrients for the next growing season.

Cotton Stalks
In a number of Sub-Sahara African countries Cotton Stalks are available in large quantities and considerable experience has been gained with this feedstock. In Malawi however one estimates that maximum only 30,000 to 50,000 tonnes per year could be used for carbonisation [6].

Earth or pit kilns which are traditionally used for wood carbonisation are not suitable to carbonize cotton stalks. The lack of air control in these kilns would cause complete combustion [6].

Maize cobs and stalks
Again earth mound kilns could not be used for the carbonisation. I have found one publication about the use as carbonized Maize cobs without briquetting [8]. A more elaborate study will be needed.

c. Processing residues
For light biomass like coffee hulls, rice husks and other shredded biomass like wood chips and timber residue carbonization in a continues carbonization system has been recommended (20,000 USD) [17,18].

d. Charcoal dust
By-product of the wood charcoal production and trading; this product has the shortest supply chain and needs only collection and briquetting [6].

11. Briquetting

Nearly all charcoal produced from alternative feedstock need to be converted to briquettes. Briquetting technologies are available in a wide capacity range, from very small to very large and with varying degrees of mechanization and automation. Agglomeration is the main technology used for producing charcoal briquettes from most of the alternative feedstocks. Since charcoal is a material totally lacking plasticity it needs addition of a sticking or agglomerating material to enable a briquette to be formed. The binder should preferably be combustible. Clay is often used as binder in small-scale applications but one prefers starch, molasses and gum Arabic in semi-industrial applications [6].

12. Conclusions

The use of charcoal is seen as the major culprit of the disappearance of huge areas of woodlands. This general feeling needs to be supported by quantitative data.

Thus the question is: "From an energy viewpoint, which is better: wood or charcoal?"

In this document the following aspects about this burning dilemma have been discussed in a quantitative manner. The results are based upon a thorough literature study combined with own observations.

- The effect the improved thermal efficiency of both charcoal and woodstoves
- Taken into account the caloric value of wood and charcoal
- Energy loss due to the cooking habit of the users
- The advantages and disadvantages of various charcoal production methods have been taken into account (from earth mount kiln to industrial units)
- Aspects related to storage and transport
- Valuable by products of the (semi-) industrial charcoal production
- Health and environmental effects of these interventions

Combination of the following two interventions will save 75 to 80 % of the presently used wood in the charcoal consumption:
- Relatively low-cost masonry "retorts" will be one of the approaches to reach a 35-40 % efficiency of the charcoal production (versus 10-15 % obtained in the traditionally earth-mount kiln).
- The distribution of affordable high efficiency cookstoves which decrease the charcoal usage with 60 % has already been successfully started by our foundation.

The final startling conclusion this study, confirmed by scientific literature, is that from an energy point of view it's better to use charcoal. Thus after modernisation and professionalization across the entire value chain charcoal will become a sustainable product.

A separate section is devoted to charcoal production from alternative feedstock.
The feedstock can be subdivided in the following classes which each having their specific supply chain

a) Energy Crops (like bamboo and eucalyptus)
b) Harvest residues (like cotton stalks)
c) Processing residues (like wood chips and rice husks)
d) Charcoal dust

For each of these products the collection of the feedstock and the transport to kilns has to be closely studied and optimized.

Recommended Reading

In the following brochures more details can be found

a) ”Charcoal the reality”, a study of charcoal consumption, trade and production in Malawi. ISBN: 978-1-84369-678-0 (2007) [1]
b) Making charcoal production in Sub Sahara Africa sustainable [4]
c) Charcoal production from alternative feedstocks June 25, 2013 [6]
d) ENVIRONMENTAL CRISIS OR SUSTAINABLE DEVELOPMENT OPPORTUNITY? Transforming the charcoal sector in Tanzania [13]
e) Multiple-Household Fuel Use – a balanced choice between firewood, charcoal and LPG [12]

A few copies of these brochures will be available when I visit Malawi in March this year.

Acknowledgements

I would like to thank the following two people for reviewing this document
Godfrey Wiliyati Kalenga; BSc Chemistry, University of Malawi, Polytechnic
Mercy Mkandawire; Bsc in Environmental Management, University of Livingstonia (Malawi)

Author Giel de Pooter; member a Dutch NGO
“Promotion of Cleaner Cooking in Malawi”

Facebook: https://www.facebook.com/Stoves-for-Malawi-543500549006169/?ref=hl
References: http://stichtingstgabriel.nl/pdfs/Progress_Report_October_2015.pdf

Terneuzen, The Netherlands, Namitete, Malawi
February 15, 2016

Appendix

A. Carbonization process

The carbonization process takes place in roughly 4 main stages.

Stage 1: drying (100-200°C)

Air-dry wood still contains 10-20 % water which has to be lowered before starting the process. Instead of using valuable wood in semi-industrial carbonisation units agricultural waste can be applied in this step.

Stage 2: pre carbonisation stage (200-300C)

Endothermic reactions take place resulting in the formation of pyroligneous liquids like methanol and acetic acid (wood vinegar).

Stage 3: carbonisation (250-300°C)

In this stage, exothermic reactions take place; the bulk of the light tars and the pyroligneous acids are released.

Stage 4: final carbonisation (300-500°C);

In this final exothermic reactions a product having a fixed carbon content of at least 75 % should be obtained. [6,19] The recommended final temperature is about 500° [19].

During the carbonization process the following liquids are released: pyroacids (in particular acetic acid), tars, water and heavy oils. Furthermore the following gasses are emitted: CO, CO_2, methanol, NO_x, N_2O, methane and other hydrocarbons. Apart from the visible smoke special attention should be paid to the very small particles Particular Matter ($PM_{2.5}$). To avoid health effects exposure of these noxious substances to the workers should be minimized.

B. Definition of efficiency

Comparison of efficiency figures from various literature sources should be done with care. The mostly used definition is how many kg charcoal containing about 75 % fixed carbon can be produced from air-dry wood containing 10 – 15 % moisture.
Based upon the overall chemical composition of wood the carbon content is about 45 % (Cellulose $C_6H_{10}O_5$). Taken into account these data the maximum theoretical amount of charcoal is 518 gr per 1000 gr wood ("efficiency 52 %").

The generally accepted caloric values of air-dry wood and charcoal are 15 and 29.5 MJ/kg respectively. According to these data at an efficiency of 51 % there is no energy loss. However in some of the articles efficiencies up to 80 % are being reported. Apparently one is applying a different definition.

C. Comparing wood and charcoal after optimization.

In 2013 Total Land Care started a project called "Malawi Fuel Switching Project". Their driving force is that they assume that charcoal stoves consume 20-30 times more wood than woodstoves (including the inefficient charcoal production). Based upon these findings it stands for reason that they strongly promote the use of woodstoves instead of charcoal stoves.

Their conclusion however, is based upon a number of assumptions which have not been supported by quantitative data.

First of all they do not seem to take into account that the caloric value of charcoal is about factor 2 larger than the caloric value of air-dried wood. Furthermore one compares an improved woodstove with a traditionally charcoal stove.

Both the Envirofit cookstoves (charcoal and wood) which are shown in this document have about equal thermal efficiencies. If charcoal is produced using the traditional kiln at an efficiency of 10 % (10 kg/100 kg wood) about 4.5 kg wood is needed for a charcoal stove compared to 1 kg wood for a woodstove. An improved kiln (assume 35 % efficiency) reduces this figure to 1.3 kg. These observations are in line with the GIZ report [12]. According to this report the wood equivalent used for an improved woodstove is 6.5 kg; for an improved charcoal stove combined with a retort kiln a wood equivalent of 7.3 kg is needed.

Other items which should be considered when comparing wood and charcoal

a) In case of woodstoves there is a significant difference between the thermal efficiency measured under optimized circumstances and the day to day practice. Nearly all woodstoves as well as the open fires need continuous attention during the cooking process. To prevent flames at the outside of the stove which cause loss of energy and damage of the stove the wood sticks have to be pushed into the fire continuously. This is common practice during e.g. the preparation of nsima, however, when boiling beans (2 hours) people forget to pay attention. The consequence is that a significant part of the wood is lost. This does not play a role when using a charcoal stove. Thus eventually the direct burning of wood might use more wood than the charcoal route.
b) The use of charcoal in the towns is mainly social and cultural determined and thus it will take a long time to change the custom of the urban people.
c) It has been estimated that only 25 % of the final costs of the charcoal are the transport costs. Transport costs for wood is estimated to be a factor of 3 to 4 higher.
d) Also the storage facilities must be larger. And storage of wood around the houses attracts snakes, rats, cockroaches, weevils, termites and thieves. Wood quality decreases due to weevils and some types of wood are also sensitive to fungus. In the rainy season it can take about 2 weeks of storage time to get an acceptable moisture content.

e) When using charcoal stoves Carbon black and PM (smoke) emissions are negligibly low. Although the smoke of the optimized woodstoves has been decreased drastically, even the most optimized woodstove will generate smoke in the kitchen. And thus imaging what is going to happen when the whole population of e.g. Blantyre starts cooking on wood (a town tormented with smog).

f) Although when using the improved charcoal stove the CO emission has been improved by a factor of 2 it remains a matter of concern. The same holds however for woodstoves which are not properly designed. As mentioned in the literature the emission of badly designed stoves might even be higher than the open fire. Therefore, we only promote stoves which have been tested in an independent laboratory.

D. Briquettes and pellets; a hype or the holy grail
(Direct use without carbonization)

The combination of briquettes made in mass production and an adequate "briquette stove" could be a booming business. Briquettes are already produced a while but as far as I know it never left its infancy in Malawi. Briquettes (and pellets) can be made from various raw materials like charcoal dust, sawdust, maize husks, coconut shells, paper waste, rice husks, coffee husks. A binder (such as cassava) is needed to hold the feedstock together. Both direct use and use after carbonisation is applied (making charcoal from the briquettes).

Initial experiences with Envirofit woodstoves did not look promising. These experiments need to be repeated under standard conditions. High pressure using a mechanical press (higher investment) seems to be necessary to obtain good quality briquettes. More elaborated testing using the charcoal stove are being planned.

E. Wood vinegar

Wood vinegar is reported to be a valuable by-product of more sophisticated charcoal production methods:
For the following applications, dilute raw wood vinegar with water in the indicated ratio.

- Kill pests by applying a 1:20 ratio to the soil
- Kill weeds by applying a 1:50 ratio to the soil
- Prevent stems and roots from rotting by applying a 1:100 ratio
- Prevent pests and mould while accelerating plant growth by applying a 1:200 ratio to the soil
- Prevent plant lice by applying a 1:400 ratio to the plant
- Enhance fruit growth by applying a 1:500 ratio to forming fruit

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