Trans-SEC

Innovating pro-poor Strategies to safeguard Food Security using Technology and Knowledge Transfer

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Summary

The report provides an analysis of upgrading strategies on waste management and nutrient cycling under Task 6.2 in Work Package 6. The work is mainly on an upgrading strategies referred to byproducts for Bioenergy (UPS No. 2) that essentially deals with conversion of agricultural biomass to obtain bioenergy that can be used in performing energy demand activities directly or indirectly related to increased agricultural production and conservation of the environment. This UPS was designed to address the following problems: inadequate utilization of crop waste products, lack of awareness on better biomass conversion methods, low value accorded to agricultural wastes and by-products, and haphazard disposal of such products. The report also provides a review of the UPS approach and potential adaptations, time frame for implementation and monitoring, the monitoring parameters and indicators.

Work at the University of Hohenheim (UHOH) under controlled conditions and the work in Tanzania involved pyrolysis of maize cobs in a laboratory at SUA and field work in Ilakala village. However, field work in Ilakala was not extensively done as there were not enough maize cobs to be shelled.

The report also provides manufacturing work and test results at SUA, preliminary test results in the field, and suggestion for improvement as provided by the UPS group. The version of the improved pyrolyzer with test results in the laboratory at SUA and in the field will be provided in the next deliverable report. Comprehensive test results at UHOH that also include performance under simulated air regulations into the pyrolyzer in relation to heating and biochar yield are provided. This is followed by recommendations on optimization of air flow into the pyrolyzer and safety aspects to the operators.

Lastly but not least recommendations on testing the pyrolyzer for energy and biochar production are provided. The intention is to make the UPS support other activities as may be seen in the field.

1. Introduction

The Trans-SEC project, with the title *Innovating Pro-poor Strategies to Safeguard Food Security using Technology and Knowledge Transfer* is implemented in Kilosa and Chamwino Districts in Morogoro and Dodoma regions, respectively. Formulation of the project went through various stages in German and Tanzania in dialogues and meetings that involved multi-stakeholders at governmental and institutional levels. The project focuses on Food Value Chains (FVC) in the two selected districts. It is run by a consortium of researchers, policy makers, and other implementation actors in Germany and Tanzania. All the chain segments and actors in crops and livestock production and the post-harvest chain were considered including processing for food and bioenergy production, waste products handling and utilization, and use of additional biomass (Trans-SEC, 2013).

During year one and year two of the project a number of activities were done to set the forward motion for implementation of the various activities. Just after the inaugural workshop an overall project baseline was conducted while at the same time experts in various fields of activities established some technical foundations. These together established benchmarks which in collaboration with the farmers generated strategies worth adapting in the target rural set ups. These were named as Upgrading Strategies (UPS), identified and prioritized by the farmers, researchers and other stakeholders as being the most suitable ones. As the project is multisectoral in nature as explained by the respective Work Packages, the selected UPS directly related to this Work Package were specifically named as follows: UPS No.2: Byproduct for Bioenergy; UPS no. 3: Improved processing; UPS no.4: Improved Wood supply; and UPS no. 5: Improved stoves. UPS 2 is under Task 6.1, UPS 3 under Task 6.2 and UPSs 4 and 5 are under Task 6.3. This particular deliverable report is for UPS No.2 (Byproducts for bioenergy), which is under Task 6.2.

2. Byproducts for Bioenergy – Pyrolysis for energy and biochar production (UPS No.2)

2.1 Overview of design and implementation

2.1.1 UPS Design

This UPS was designed to address the following problems: inadequate utilization of crop waste products, lack of awareness on better biomass conversion methods, low value accorded to agricultural wastes and by-products, and haphazard disposal of such products. One of the solutions to these problems is pyrolysis of dry residues (maize cobs) to provide thermal energy for drying, roasting or cooking applications, and biochar, which can be used as soil amendment or energy carrier. Pyrolysis of maize cobs which is an important byproduct in Kilosa district is implemented in Ilakala village where a farmer group was formed and used as a laboratory for adaptation, adoption and dissemination. A TLUD reactor will be first of all designed, constructed in a metal workshop at SUA, and undergo both laboratory and field testing for the pyrolysis of maize cobs. During pyrolysis water boiling can also be achieved.

2.1.2 Review of UPS approach and potential adaptations

a) Economic considerations

Cheaper and decentralized options for construction will be considered. Such materials as spent oil barrels may be considered as the cheapest but use of ferro-cement tanks with metallic inner core and chimney could be another option (stationary reactor).

b) Formation of a business oriented group

This is important for sustainability of the technology

c) Establishment of business model

- Take various alternative designs if available
- Establish production costs: materials, labor
- Determine the amount of maize cobs available from the group
- Advantages accrued from its use: biochar (for kitchen garden–analyze chemical composition; establish how much should be used per unit area of land), equivalent time for boiling versus use of conventional fuels, use of biochar as energy source.
- Calculate return on investment

d) Multi-use: Boiling of drinking water

- Customization to water boiling (drinking water; stiff porridge; soft porridge; blanching of wild vegetables where applicable) as already influenced by the respective UPS group

e) Fixed installation / digging in for insulation

- Digging into the ground may be tricky
- Consider insulation with soil plaster wrapped within a monkey wire/coffee wire/chicken wire; alternatively use rice ash plaster; or soil-rice ash composite. Note: Proper emptying must be considered.
- Consider insulation by making a hollow space using thin mild steel sheet.
- Provision of small holes at the bottom (say, 8 holes in the space between the wall and the central core)

f) Creating manual / protocol of knowledge: Construction details and use

g) Publicity

2.1.3 Reviewing minimum and maximum number of repetitions

Continuous assessment of performance until the end of the project

- At SUA: October 2015 - February 2016; July - August 2016 by using maize cobs, wood shavings, etc.
- At Ilakala: July –August 2016

2.1.4 Reviewing UPS monitoring parameters/indicators and baseline information requirements

a) Group management issues

i) Group Name......................

ii) No of members present ....Male ....Female.............

iii) From which sub villages are the members of the groups come from..........

iv) Are there any increase or drop up of members? Yes/No. Reasons for increase or drop out...

v) Does the group leadership exist (chair person.........., secretary..........., treasurer...........) (Yes, No)

vi) How often do group members meet (intervals)?

vii) How many times did they meet since their inception?

viii) What do they discuss when they meet?

ix) Does the group members keep record? If yes, which records?

x) Does the group have a constitution?

xi) Do all members have a copy of the constitution?

xii) Does the group have a working plan? Yes/No. If yes, how far has their plan implemented?

xiii) What is the status of the UPS group registration?

xiv) Who makes decisions for group activities?

xv) What are the challenges faced in managing the UPS group?

b) Technical and socioeconomic performance

Socioeconomic Performance

i) Who is operating?
ii) Where is the pyrolizer located?
iii) How often is it translocated to another location?
iv) Availability of agricultural residues for feeding pyrolizer (high, medium, low)
v) Time (hours *per week*) spent on operating the *pyrolizer.*
vi) What is the benefit of operating (Nr. of cookings done, charcoal making)?

Technical Performance

i) Time used for operating the pyrolyzer: time for boiling water, time for completion of pyrolysis, time required for cooling of the pyrolyzer, time for emptying the pyrolyzer.
ii) Re-use of bio-char in stoves (yes/No/ how much per meal) in comparison with unpyrolyzed cobs – determine time for heating/boiling equivalent amount of water in comparison with unpyrolyzed cobs and firewood or temperature variation with time.
iii) Determine the amount of conventional fuel (firewood and charcoal) used by the UPS group for cooking stiff porridge/boiling water
iv) Use of small biochar particles for applying to crop fields (yes/no)
v) Use of ash for applying to crop fields (yes/no)
vii) Additional time required for handling / per day if any
viii) Problems experienced in operating the pyrolyzer
ix) Estimate productive time for operating the pyrolyzer per week

c) Gender issues

UPS Participation and Control

i) Is there a difference in male and female participation in: Implementation…………, Training……………, Meetings for UPS…………….?
ii) What is the influence of the UPS on social issues (conflicts, relationships, meetings, etc?
iii) What influences the male, female, youth participation on UPS? …………..
iv) Are there differences in decision making for a) men b) women regarding UPS income and expenditure?
v) Regarding investments in the UPS, are there affordability differences? Which ones for a) Male……………….. b) Female………………….. c) Youths…………….

Changing Gender Roles and Relations

i) Are there any changing roles during and after UPS implementation?

ii) After implementation are the traditional roles changing? …………………….

iii) Are there non-traditional roles changing? ……………………..

iv) What is the change of workload related to UPS? Is the overall workload increasing…… (on whom) or decreasing…….(on whom)?

d) Status of implementation

i) Has the group started implementation of UPS? YES/No; If YES when was UPS implementation started?..........

ii) If the group has started UPS implementation,

- How many farmers were trained on the UPS implementation?.......
- How many farmers participate in UPS implementation…………..?
- What is the level of UPS implementation among the group members........?
- How is the UPS being implemented?......................

iii) Do the trained farmers train others in their villages? YES/No. If YES, how many?

iv) Are there farmers who have changed the UPS groups? YES/No. If YES, why?..

v) What are the challenges faced during UPS implementation................

vi) Have members of the group allocated land or other requirements for UPS implementation as was agreed during group formation? ....

vii) Have the groups received any support from the project? YES/NO. If YES, what is the support received from the project...........................

e) Economic analysis: this will be covered once the business model is established

2.1.5 Planning time schedule for monitoring activities

- University of Hohenheim will continue with upstream testing of maize cobs, Jatropha shells, etc.
- SUA will continue with on farm and on station experiments where possible and depending on fuels available.

2.1.6 Milestones

Finalization of testing report

Implementation report / technical fabrication mid of next year

Publications

Modelling and technical feasibility of charring applications in a TLUD reactor with multiple fuels / mid next year

2.1.7 Publications

- Intani, K., Romuli, S., Munder, S., Wüst, D., Müller, J., 2015. Optimization of carbonization of wood chips using multi-purpose Top-lit Updraft Reactor (TLUD). In proceedings Thermochemical processing of renewable feedstock into fuel, chemicals and polymers. 16-19 November, Kazan, Russia.
- Romuli, S., Munder, S., Wüst, D., Müller, J., 2015. Assessment of carbonization of wood chips using a multipurpose top-lit updraft reactor in rural areas. In proceedings Tropentag 2015: International Research and Food Security, Natural Resource Management and Rural Development. 16-18 September, Berlin, Germany.
- Munder, S., Romuli, S., Intani, K., Wüst, D., Müller, J., 2015. Byproducts for bioenergy - advanced firewood substitution by simultaneous cooking and charring application. In proceedings ICOS-International Conference on Soil. 04-07 May, Tirana, Albania.

2.1.8 Roles and expectations in UPS team

There are no changes on roles from the initial project set-up.

2.1.9 Other issues

None

2.2 Methodology

2.2.1 UPS location

This UPS was implemented in Ilakala after conducting some laboratory tests at SUA. Implementation activities were subdivided into five steps, namely: formation of a business oriented farmers group, project planning and feasibility, construction of one unit of pyrolyzer, and training of farmers on operations and management.

2.2.2 Establishment of business oriented farmers group

- A two-days workshop was conducted in each village involving the 150 HHs and beyond.
- UPS group of 20 HHs was formed towards the end of September 2014 in Ilakala.
- Decision to join the group was voluntarily achieved by the individual HHs themselves, in addition to fulfilling the following criteria:
    - Ability of the farmer to invest in the technology
    - Capacity of producing large amount of maize cobs

2.2.3 Project planning and feasibility

Feasibility study has not been conducted because the current struggle is to make the technology work. Upon having a working technology feasibility study on this UPS will be done and consider the following factors:

- Availability of by-products
- Cost of collection
- Competition with other users
- Cost/Benefit analysis

2.2.4 Redesign and manufacture of the pyrolyzer at SUA

The top-lid-up-draft (TLUD) reactor that was previously designed at UHOH was re-designed at SUA to include an off-set depression on the top lid directly facing the off-set chimney. The depression was about 7 cm deep with a diameter of 28 cm to accommodate a modest size pot for water boiling or cooking.

2.2.5 Testing of the pyrolyzer at SUA and in the field

After manufacturing and trial tests at SUA the reactor was taken to Ilakala village for use with the UPS group on experimental basis. The test was conducted in three sub-villages in Ilakala namely Shuleni, Miogoni, and Mashineni and involved at least 5 farmers. One day was devoted in each sub-village and involved moving from one area to another. At each sub-village, about 15 kg of maize cobs were pyrolysed in the reactor and at the same time water was boiled using the depression on the top lid.

Pyrolysis is defined as thermal decomposition of biomass in absence of oxygen. Therefore, what was done was actually partial pyrolysis. As operating the reactor in the beginning resulted in inadequate heat to boil water, trial and error testing on the air gap at the bottom was done to obtain biochar and at the same time be able to boil water. The aim was to strike a balance point. The following solutions were proposed:

1) Partial pyrolysis by fully opening the bottom vent until water was boiled, after which the process was continued for 5 more minutes before fully closing the vent. It was expected that full pyrolysis could continue after all the entrenched oxygen was expelled with stack gases.
2) Complete pyrolysis (bottom lid fully closed) with the barrel filled by one third, two thirds, or fully loaded for a maximum period of 3-6 hours. In this case water boiling is just an option.

Parameters of interest:

Ambient conditions: solar radiation, temperature, humidity, and wind speed

Pyrolyzer barrel temperature: on the sides at near the bottom, one third, two thirds and near the top measured from the bottom to the top end of the central core; at the top close to the pot; at the chimney exit.

Boiling water temperature: from the start to the time of removal from the doomed bottom of the pot's support. We need to get a pot with a doomed bottom.

Stack gas composition: carbon monoxide, carbon dioxide, methane, oxygen, and other gases. This will require the use of *Orsat Analyzer (To explore on possibility of using it in the field)*.

Weight: cobs before pyrolyzing, pyrolyzed cobs, and ash. The difference will denote the amount of burnt biomass and water removal. *Difference = dry matter in cobs-dry matter in pyrolyzed cobs + ash*

Physical observation: colour of smoke, etc.

2.2.6 Construction of a modified TLUD based on farmers views

After some trial tests with the UPS group at Ilakala village some shortcomings were observed and some of the recommendations for improvements were made. This resulted in manufacturing of a shorter TLUD with provision for insulation and the chimney that is redirected away from the center (*Figure 2.1 below*). However, this is yet to be tested.

Figure 2.1 Improved TLUD reactor based on the Farmer's recommendation

2.2.7 Monitoring

Monitoring was done by a group of experts from ARI and MVIWATA on the basis of indicators mentioned in 2.1.4. The following means were used for information gathering:

- Informal and formal surveys by members of the consortium
- Data gathering by students and researchers
- Telephone communications
- Daily monitoring and supervision by on-station personnel

2.2.8 Controlled condition testing at UHOH

A test rig was constructed to hold a 0.216 m³ barrel as central element of a TLUD-type reactor. The bottom was perforated with 32 holes of 12 mm diameter each, placed in consistent distance on a circular pattern. The centre held an opening for air inlet regulation. A perforated cylinder of the barrels height was placed over this opening.

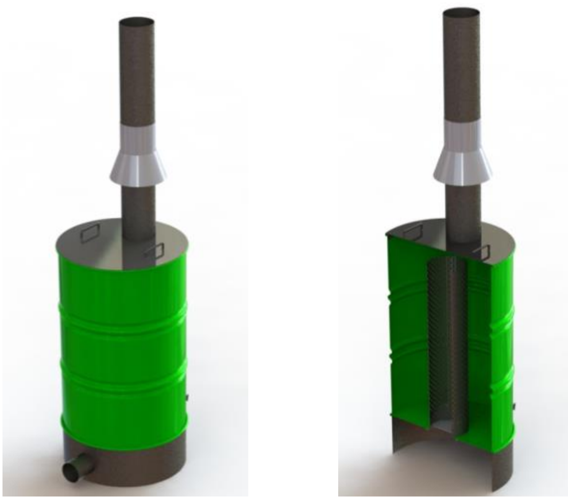

Figure 2.2: TLUD-reactor core elements, left: General view with closed lid, right: cutaway view through barrel and perforated cylinder

The bottom of the barrel was extended with a cylindrical air chamber which had a flange connection to the air suction chamber, which served as the only inlet for primary air. Figure 2.2 clarifies the general structure. Exhaust air was guided through an eccentric chimney placed on the top lid. Via the eccentric construction, the lid could serve as heat exchanger for cooking operation. The chimney was augmented with secondary air inlet slices and a thin steel cover for wind protection and air flow regulation. The reactor was mounted to a test rig with proper thermal insulation to create repeatable conditions and to facilitate operation by one person. Thermal insulation was acquired by a fill material (Agroverm, Isola Mineral wollewerke, Sprockhövel, Germany) with very low thermal conductivity, weight and density. The reactor was mounted tiltable to a frame as shown in Figure 2.3.


Figure 2.3:Test rig in different positions, left: prepared for filling, probes in transport position, right: tilted for taking out of produced char.

The thermocouples of a 3x3 matrix placed on the lid were flexibly mounted inside of holding pipes, which themselves were welded to a tray. By the flexible structure of the installation, temperature driven displacements of the reactor lid were compensated, resulting in permanent contact with the probe heads. Figure 2.4 shows the matrix tray and its placement on the lid. The whole reactor, as rendered CAD image and as a photograph is shown in Figure 2.5.

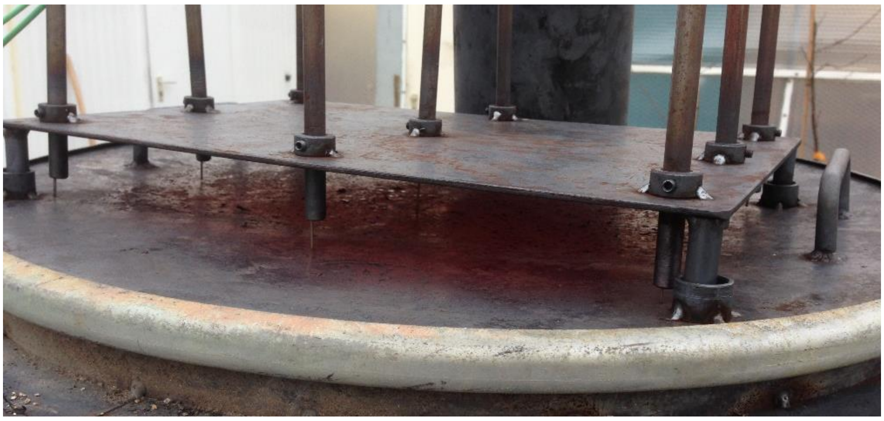

Figure 2.4 Matrix tray with thermocouples and fixing sleeves.

The air flow was measured via a vortex sensor (Vortex VA40, Höntzsch, Waiblingen, Germany), laminarization of the inlet air was realized via an 3300 mm long steel pipe.

Figure 2.5: Test rig in preparation for experiments

Temperature was measured at 20 different positions with type K (NiCr/NiAl) thermocouples of class 1 (Typ K Thermocouple, Electrotherm, Stuttgart, Germiny, -270 – 1370 ± 1 °C). On the matrix, 9 positions were recorded as shown in Figure 2.6, the reactor held 8 measurement positions, 2 (Figure 2.7) were in the chimney and one sensed the ambient temperature.

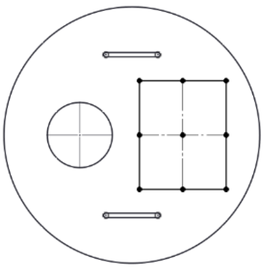

Figure 2.6: Lid with 3x3 matrix

Mass change during charring operation was recorded with an industrial balance (PFWA-KB30, IHG Industriewaagen, Renchen, Deutschland 0-3000 ± 0.5 kg). The main air inlet was regulated to 100, 80 and 50 % opening as pictured in Figure 7. The influence of primary air mass flow on temperature, mass loss, and process duration was tested in a one-way ANOVA.

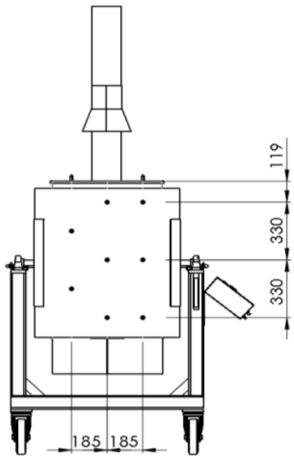

Figure 2.7 Thermocouples in reactor and chimney

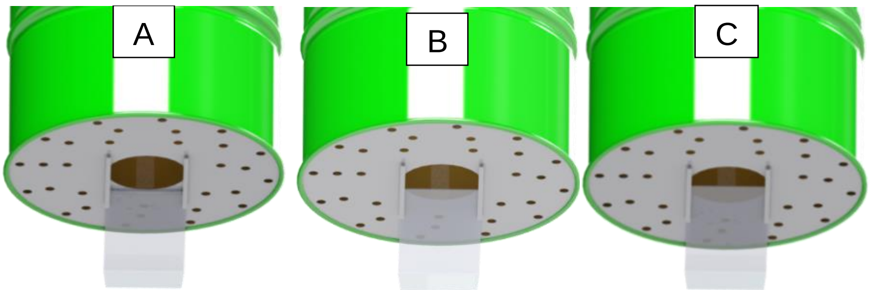

Figure 2.8 Air opening at 100% (A), 80% (B), 50% (C)

2.3 Achievements / results

2.3.1 Fabrication work and testing at SUA

The 1st version of the TLUD was manufactured at SUA around July 2015. Due to the low maize harvest that was realized in 2015 there was insufficient amount of maize cobs when the reactor was tested. However, the small amount of cobs that was available was used to see whether the reactor works. The work was on trial and error basis because there was no known standard pyrolysis period made available.

When the barrel was full of cobs and the air gap at the bottom was closed it resulted in partial charring of the cobs when the process was stopped after 3 hours. Another trial was stopped after 6 h which resulted in complete charring but with more ash than simply pyrolyzed materials. When the reactor was filled to just one third of the barrel column and the air gap at the bottom partially closed it took about 40 - 48 minutes for water to boil. Extending the reaction time to 50 minutes was regarded as end of the process and when emptied all the cobs were burnt. The amount of biochar obtained was almost 30% of the cobs by weight. More results are shown in Table 2.1.

Due to lack of sufficient materials to repeat the test no more work was done at SUA except taking the reactor to the farmers for another test to seek their views.

2.3.2 Field test at Ilakala

2.3.2.1 Test results

As there were no enough materials for sufficient testing of the TLUD only a few trials were made, basically for seeking views for improvement of the TLUD design. Some test results as obtained from the UPS group at Ilakala village are presented in Table 2.1. It took about 10 minutes to fill the reactor and the pyrolysis process took about 100-120 minutes. Initially the air gap at the bottom was fully opened and after the water boiled the air gap was closed.

Table 2.1 Some Test Results of the TLUD at Ilakala Village

Date	Sub-village	Pyrolysis period	Amount of cobs (kg)	Amount of biochar (kg)	Biochar/ cobs ratio	Amount of burnt cobs	Time for water to attain boiling point	Comment
25th August,2015	Shuleni	100	15	3	0.200	4	27	Clear water
26th August 2015	Miongoni	115	15	4.57	0.305	0	40	Muddy water
27th August 2015	Mashineni	120	15	5.5	0.367	0	38	Clear water
Average		**111.67**	**15**	**4.36**	**0.290**	**1.33**	**35**	
Standard deviation		**10.41**	**0**	**1.26**	**0.08**	**2.31**	**7**	

From the Miongoni and Mashineni sub-villages the amount of biochar produced was almost 33% of the original weight of cobs. Time taken for water to boil at Miongoni was 40 minutes, which was higher than 27 and 38 minutes, for Shuleni and mashineni sub-villages, respectively. This could be due to use of muddy water at Miongoni.

Due to very poor maize harvest which led to the absence of maize cobs in the area the results made were just provisional as thorough testing will be done from July 2016. However, some pertinent observations were made by the UPS group even if the few maize cobs that were used were brought by the researchers from other areas. Those observations are indicated in the questions and answers in Table 2.2.

Table 2.2 Responses from the UPS group

SN.	Question asked	Response from the UPS group
1.	Are the members of the UPS group willing to cook while standing? YES/ NO	*20% are willing, 80% prefer sitting on a chair or kigoda (short three stand round chair).*
2.	If the answer in Q1 is NO, which cooking style do they prefer? Sitting on mat, sitting on short chair (kigoda) sitting on normal chair	*See the answer above*
3.	How long do they boil water for tea/coffee? (5 min, 10 min, 15 min, 20 min….)	*Assumed to be less than 20 min (to be assessed)*
4.	What is the weight of firewood used for boiling water for tea/coffee?(1kg, 2kg, 3,kg …etc)	*Not yet quantified but assumed 20 kg per day (to be assessed).*
5.	How long do they cook rice?	*Estimated to be 45 min*
6.	How long do they cook relish?	*Estimated to be 30 min*
7.	How long do they cook stiff porridge	*Estimated to be 20 min*
8.	Is the reactor safe for use (temperature)?, Yes/No	*No*
9.	If the answer in 9 is No, where the improvement should be done?	*It is very hot, not safe for kids below 15 years hence need insulation.* *It is too tall, need to be shortened for easy utilization by all household members* *It produces a lot of smoke at the chimney*
10.	Are there other challenges of using the reactor? Yes/No	*Yes*

11.	If the answer in 10 is Yes, what are those challenges?	- *The reactor is heavy and difficult to translocate.* - *Availability of maize cobs is seasonal* - *The depression for putting a pot is too deep.* - *Time for boiling water is longer than when firewood is used.* - *Difficult to fabricate under village conditions where the raw materials (steel barrels, steel pipes, welding rods, etc) and electricity are lacking*
12.	Is the biochar obtained during pyrolysis suitable for cooking?	- *It is fast to ignite and good for starting a charcoal stove* - *It extincts fast on combustion, hence not appropriate for cooking.*

Table 2.3 Estimated Manufacturing Cost for One Unit

SN.	Item	Cost (T. shillings)
1.	Drum, central pipe, and metal sheets	80, 000.00
2.	Manufacturing cost (machining + Labour)	70, 000.00
TOTAL		150,000

Two men and one female actively participated in all the three testing trials of the reactor.

2.3.2.2 Suggestions for technical improvement

- Redesigning of the reactor to conform to the UPS group wishes: reducing height provide insulation on the sides, make two depressions to accommodate two cooking pots, redirecting smoke away {Not: presence of smoke is a sign of inefficiency}.
- Redesigning of the reactor to make use of stack gases
- Reducing the amount of air initially so as to produce quality biochar

2.3.2.3 Manufacturing of an improved TLUD

Based on recommendations from the UPS group, the TLUD has been modified to include insulation chamber, two depressions for cooking, and redirection of stack gases away. Testing of this unit will begin soon to allow for any improvement before the next harvest season. However, the task team is still struggling to obtain smaller size barrels to make a light weight TLUD.

2.3.2.4 Recommendations for adoption

As it was preliminarily observed, use of the TLUD to boil water may face some challenges and remain with biochar production as the main objective. The amount and quality of biochar produced depends on performance of the pyrolytic process. However, no proven results of using biochar from maize cobs are known to have been reported. While efforts to improve pyrolysis of maize cobs for energy production purposes are afoot there is need to establish the merits of pyrolysis strictly for obtaining biochar as a soil amendment material. In so doing, the following issues need to be addressed:

- Potential availability of biochar
- Results of using biochar as a soil amendment material
- Can biochar improve plant growth compared with use of microdosing and other modes of fertilizer application?
- Establish the possible amount of use that can create significant improvement.
- Conduct economic analysis of TLUD on each of the alternatives (heat and biochar production) or both.

2.3.2.5 Monitoring

The farmers group on this UPS started with 23 members and by December 2015 it was not known how many have remained because the group is not actively engaged in this UPS as the technology is still undergoing improvement and testing. So far the group has no leadership because the leaders who were nominated initially absconded due to delay of the UPS implementation. Due to this the group has not conducted any meeting yet.

2.3.3 Results and discussion at UHOH

2.3.3.1 Laboratory results

Air mass flow for the different primary air openings was significantly different. Figure 2.9 gives the course of air mass flow during the experiment. The 100 % setup reached a plateau at 0.055 kg/s, the 50 % setup at half the value, around 0.027 kg/s. The 80 % opening's air mass flow lies in between. All are significantly different from each other.

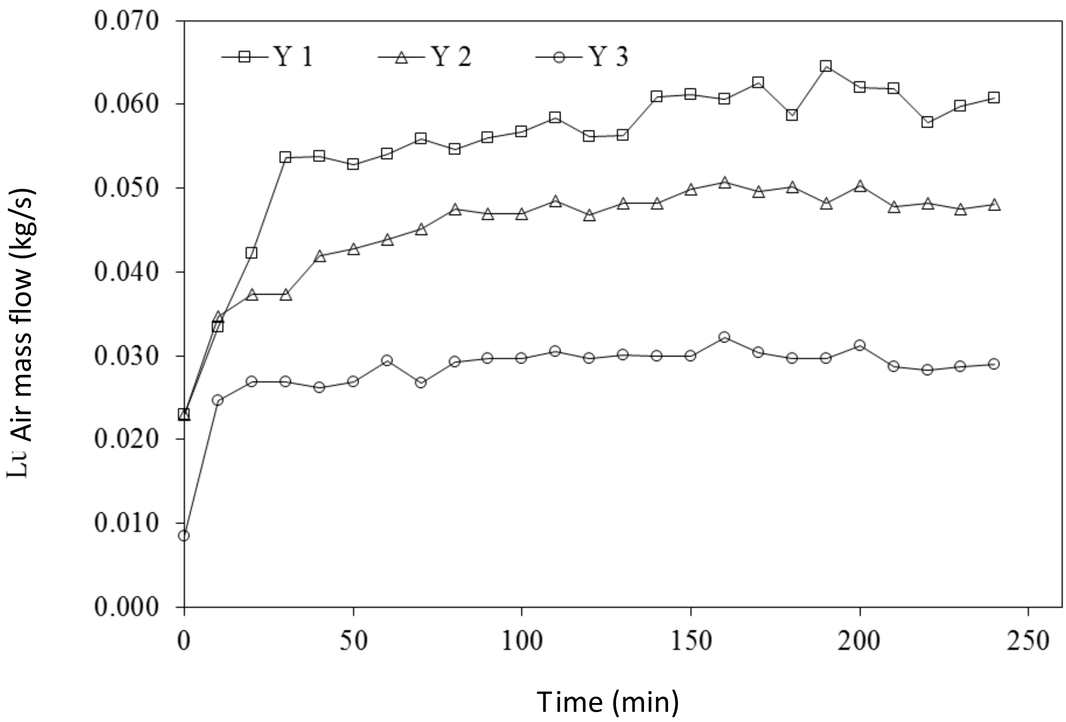

Figure 2.9 Air mass flow of primary air means through repetitions.

Mass loss during operation shows a nearly linear trend, as visible in Figure 2.10. At approximately 150 minutes, the rate of decrease changes.

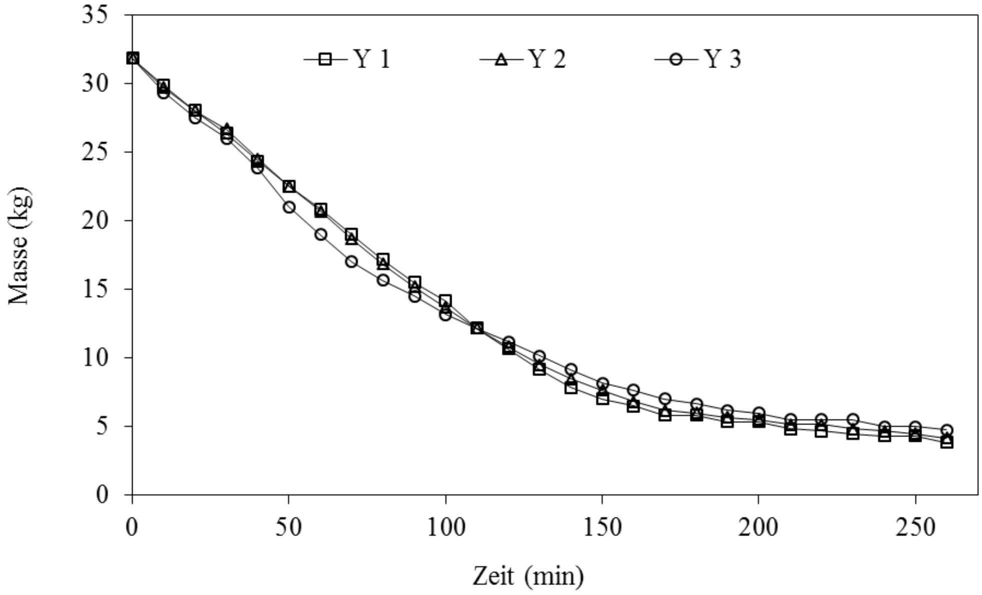

Figure 2.10 Mass loss during operation, means of treatments.

This shifting point represents the meeting point of biomass conversion phase and the char conversion phase, which both can be expressed by different conversion rates. Solving of the differential equations of both linear functions yields the shifting point, at which the biomass conversion is complete. At this point, the remaining char inside the TLUD reactor becomes exposed to oxygen and thus is also thermally degraded, resulting in lower yield. Therefore, the shifting point is the time at which operation should be stopped to obtain maximum yield. Figures 2.11, 2.12 and 2.13 show the shifting points for all primary air treatments.

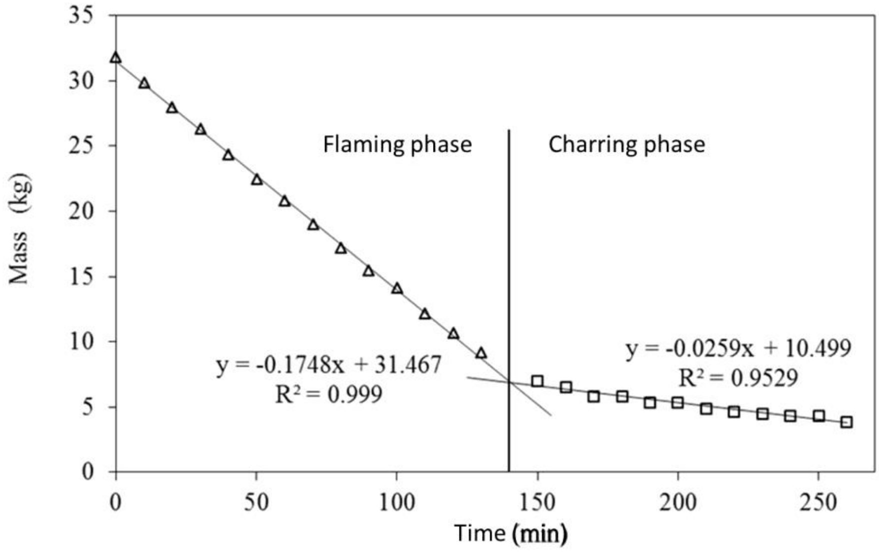

Figure 2.11: Mass loss and regression of 100 % treatment.

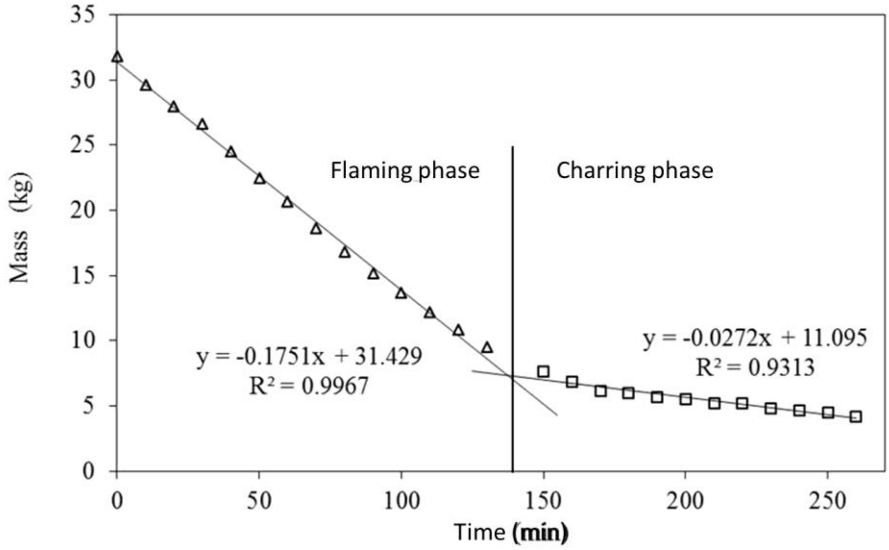

Figure 2.12: Mass loss and regression of 80% treatment.

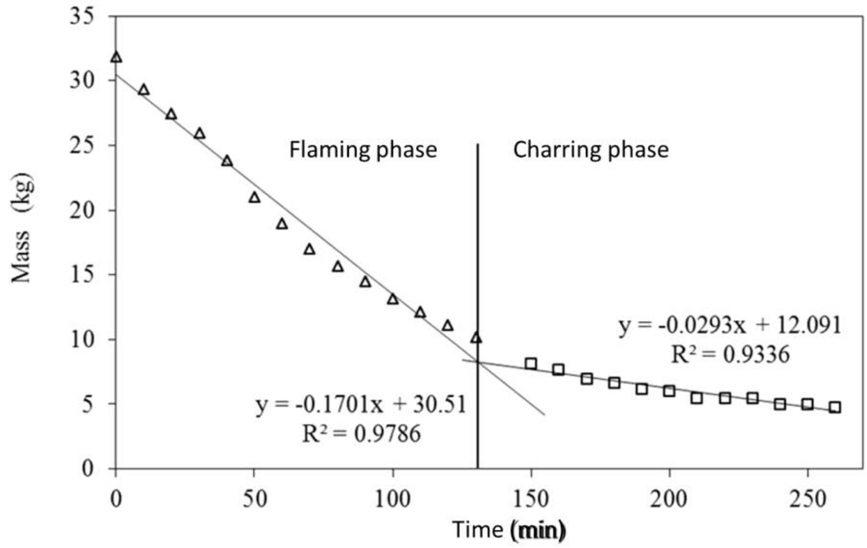

Figure 2.13 Mass loss and regression of 50% treatment.

Regressions could be fitted for the first phase of the 100% treatment with a very high coefficient of determination. The acquired shifting points and yields were significantly different between the 100% and the 50% treatment as shown in Table 2.4, whereas the influence of different air opening on the air mass flow, heating rate, char yield and composition are also presented. A significant difference of air mass flow was detected among the air opening. Char yield and heating rate at air opening of 50% was higher than the other air openings. However, no significant difference was identified on the element content of char.

Table 2.4 The effect of primary air setting on air mass flow, heating rate, char yield and composition

Primary air opening, %	**100%**	**80%**	**50%**
Air mass flow, kg/s	0.056[a]	0.042[b]	0.026[c]
Heating rate, K/min	5.57[ab]	5.54[a]	6.82[b]
Char yield, %-m/m	19.6[a]	23.0[a]	25.8[b]
Elemental analysis of char			
Ash, %	2.65 ± 0.13	3.70 ± 1.32	2.16 ± 0.66
Carbon (C), %	89.18 ± 0.99	89.49 ± 0.58	89.96 ± 3.90
Nitrogen (N), %	0.03 ± 0.00	0.04 ± 0.03	0.11 ± 0.04
Hydrogen (H), %	1.85 ± 0.13	1.82 ± 0.04	2.21 ± 0.02

The temperature distribution when air opening was set for example to 100% is presented in Figure 2.14. Similar pattern was also obtained with other sizes of air opening. It can be seen that after ignition from the surface, the heat was rapidly transferred from the top to the bottom. High generated temperature exhibited beneficial condition in producing high quality of char. Insulation of the reactor is highly recommended in order to minimize heat loss. After 150 minutes operation, the heat was thoroughly distributed inside the reactor. Simultaneously, the temperature of matrix increased to 300 ^{o}C and remained constant for more than 3 hours. The time duration was sufficient for cooking activity in rural areas. Temperature of exhaust gas was 600 ^{o}C, which also revealed potential of remaining energy to be further utilized such as Stirling engine or steam boiler.

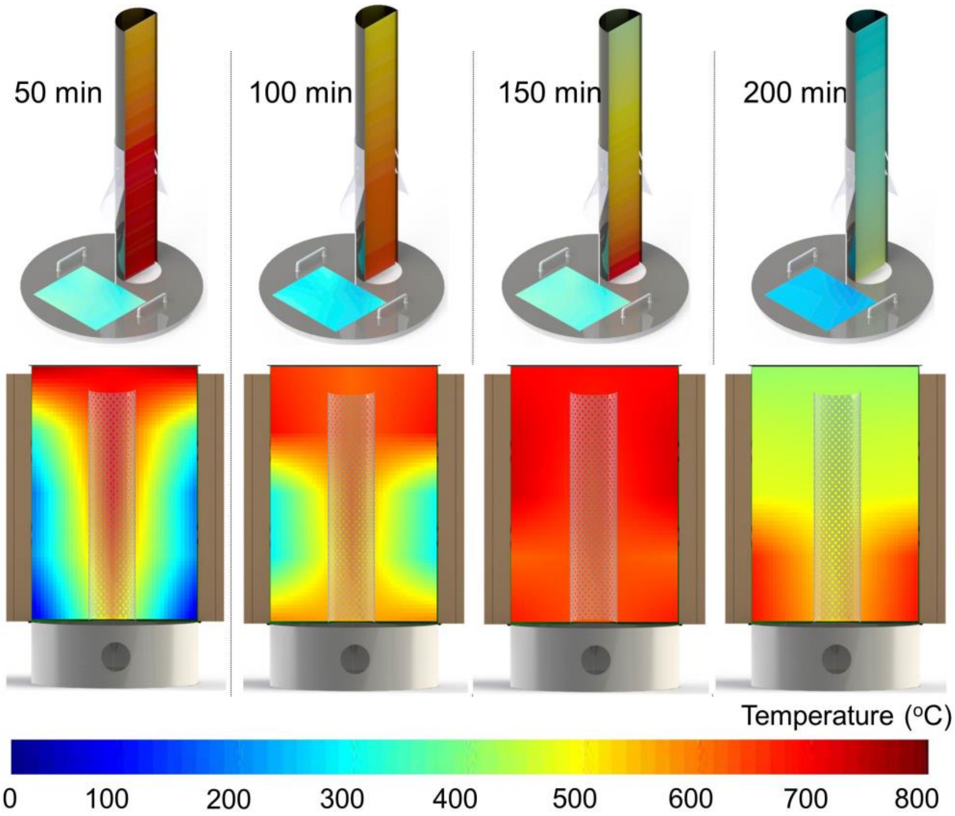

Figure 2.14: Temperature of chamber, exhaust, gas and cooking plate at 50 min a), 100 min b), 150 min c), and 200 min d), when air flap was opened 100%.

The results of air flow simulation at different air openings (100%, 80%, and 50%) are shown in Figure 2.15. Natural draft force generated during thermochemical process was predicted and distinct air flow arrangements were detected as the air opening was adjusted. As the ambient temperature becomes cooler, the draft force will be escalated. At the first time, the air was consistently fed from the bottom to the top layer of biomass where the initial thermochemical process occurs, and was emitted through chimney.

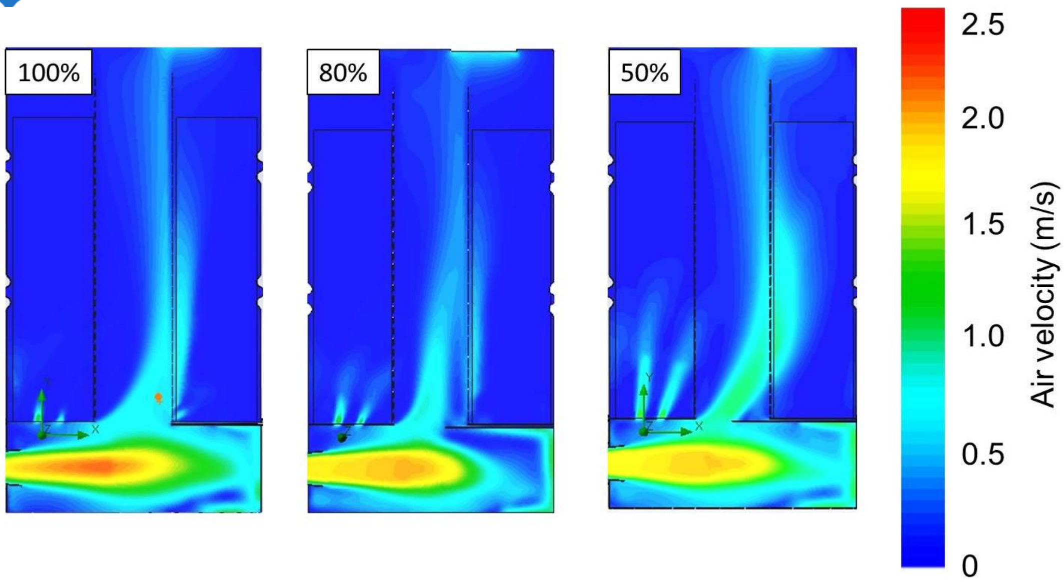

Figure 2.15: Air flow simulation using computational fluid dynamic at 100%, 80%, and 50% air opening.

Lower air opening forced more air flow through the perforated holes. Therefore, the simulation also revealed that the material characteristics such as density and porosity are important to be investigated in order to determine the optimal setting of air flow. The higher porosity biomass has, the less air is required through perforated cylinder.

2.3.3.2 Lessons learned and adaption

TLUD reactor is highly flexible to be upscaled or downscaled with respect to the availability of the construction material such as oil barrel, perforated cylinder, and insulation material. The use of CAD has allowed the engineers to easily develop technical guidelines in designing and manufacturing the reactor.

It is suggested to centralize the air inlet through a pipe as shown in the experiment, in order to enable air flow adjustment during operation. As for the insulation of the TLUD reactor in Tanzania, clay or fibres are suggested to be applied. The other option is to bury the reactor in the soil, which acts as the insulation material. As for the air inlet, a channel which connects ambient air and the bottom part of the reactor is recommended. Through this method, the heights of the reactor on the ground can be reduced and people can operate the reactor while sitting. However, due to complexity in discharging the char after the process, an unloading system without flipping the reactor should be investigated.

TLUD reactor should not be operated inside the house due to gas emission from the chimney. Therefore, a training program on how to use the reactor effectively, properly and safely in rural areas should be conducted. Further development could consist of constructing a mobile unit and running the reactor using other agricultural waste such as maize cobs and *Jatropha curcas* L. seed shells.

3. Recommendations

It is recommended to continue perfecting the pyrolyzer as per the recommendations from the UPS group and any other idea as may be seen from the situation in the field. Testing in the laboratory and in the field should be continued to find the optimal time for pyrolysis for heating purposes as well as production of biochar. The use of biochar and its advantages, particularly for kitchen gardens need to be explored further. Positive results from such uses will increase chances of acceptability of the pyrolysis of crop residues by using the current pyrolyzer or the traditional charcoal making technologies available in the village.