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"Experience from Rural Electrification in Uganda: A Case Study of a Husk Powered System in Tiribogo Village"

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ABSTRACT

To address the need for electricity in some rural communities in Uganda with seasonal agricultural waste or biomass, we need a biomass to electricity conversion system. A low-cost biomass to electric energy conversion husk powered system was imported from the Husk Power Systems of India. The system was installed in 2012 in Tiribogo Village, Muduma Parish in Mpigi District supplying 32kWe power to an isolated power grid. The system has operated since October 2012 with a daily usage of 7 hours. The biomass flow rate of 30 kg/hr for maize cobs and 25 kg/hr for coffee husks. The power output measured was 34 kW with line voltage of 244 V/ 50 Hz and phase voltage 422 V with a power factor of 0.85 at the generation side. The specific fuel consumption was 0.88 kg/kWh for maize cobs and 0.74 kg/kWh for coffee husks. The system electrical efficiency was 20.5% for maize cobs and 30.2% for coffee husk. The solid waste products generated were 12% for maize cobs and 10% for coffee husks of the total biomass fuel put into the gasifier.
A software business model was generated using RETScreen software, considering the total cost of inputs and cost sales, the unit cost of power was found to be US$ 0.259 (UGX 686/=). The business simple payback was 3.3 years for maize cobs and 3.4 years for coffee husks. The break even period for the business was found to be 6.2 years for maize cobs and 6.3 years for coffee husks respectively if all power generated is sold. The fact that maize cobs were offered free from the community with transport cost of USD 15 per ton and coffee husk were bought at a rate of USD 40 inclusive transport per ton caused the difference in the financial parameters. In conclusion the operation of a 32 kWe power plant was found satisfactory using the local biomass and it produced more power than the community could consume or buy at that time therefore it is recommended for the rural communities generating 7 tons of annually.

Keywords: Rural electrification, isolated grid, Biomass, Husk power system

1.0 INTRODUCTION

Uganda's annual energy consumption per capita is still low at only 58.2 kWh compared to Kenya at 133.4 kWh, Tanzania 73.14 kWh, DR.Congo 122.5 kWh and Sudan 110,71 kWh as published in 2012 (www.Indexmundi.com, 2012). The main energy supply, in Uganda, is derived from biomass sources at 93%, followed by petroleum products 6%, leaving electricity at only 1% (Baanabe, 2012). The recorded national electricity access in 2007 was about 9% which is a very low figure compared to other countries like Singapore 100% and Egypt with 80% (UNDP, 2009).These statistics show little hope for rural areas to access clean energy from the national grid. Biomass based small-scale electricity generation has shown some success in other countries. However site-specific needs and biomass resource assessment need to be taken into account in selecting and implementing a biomass-to-electricity conversion technology.

Our task was to study the husk powered system characteristic performance and operation challenges in the Ugandan environment. In this study, characteristic performance and operation challenges of the Husk Power System (HPS) were established. The HPS is an Indian Technology installed in Muduuma, a rural area in Mpigi district. The fuels used in the plant were the available coffee husks and maize cobs in Mpigi. The fuel type was selected based on their availability in this area, close particle size proximity and chemical composition closeness with the biomass used in the system by the HPS designer in India.

3.0 Samples and methods

Sample preparations

The 12 samples of each biomass (coffee husks and maize cobs) were taken to the Laboratory at the College of Engineering, Design, Art and Technology at Makerere University where the tests and analyses were carried out. The samples were homogenized by through mixing before carrying out the tests.

3.1 Moisture content

Moisture content was determined using the DIN 51719 or ASTM-E 1755-95 standard. Three samples of each biomass weighing a minimum of 1100 mg were put in an open crucible and then placed in an Eltra Thermostep – Thermographic analyzer. The thermostep is internally programmed to heat the sample up to 103^{o}C and monitor its weight stability of +/- 0.001g is achieved then stop and give the results.

3.2 Proximate analysis

The themostep was used in the proximate analysis to determine the volatile matter, fixed carbon and ash content. A sample of a minimum weight of 1100mg is put in the Thermostep, a non-oxidizing gas is injected in the Thermostep then temperature is raised to 950 ^{o}C and held for 7 seconds. The sample is then weighed internally and the weight loss of sample represents the volatile matter sample. The remaining sample mass in then cooled to a temperature of 750 ^{o}C and held for 1s and weighed. The remaining weight is the fixed carbon in the sample. Oxygen is then introduced and to burn the carbon till no change in mass. The final residual weight of sample is the ash content in the biofuel.

2.6. Heating value

. The higher heating value of the biomass_was measured using an IKA C2000 Digital bomb calorimeter. Samples weighing 1000 mg were placed in the bomb calorimeter and subjected to complete combustion in an adiabatic environment. The Higher Heating Value (HHV) was calculated from measured temperature increase in the adiabatic system.

RESULTS AND DISCUSSIONS

The following were our findings based a 22 day study of the husk powered system at the case study site in Muduuma- Mpigi District.

4.1 Biomass properties

The biomass properties used in the HPS were as shown in Table 1.

Table 1 Biomass properties

Parameter	**Coffee husks**	**Maize cobs**	**Units**
Bulk density	**348.3**	**283.8**	**Kg/m3**
Moisture content	**13**	**15**	**-%**
Volatile Matter	48	56	**%**
Fixed carbon	**48.43**	**43.23**	**%**
Ash content	**3.3**	**5.2**	**%**
Lower Heating value (LHV)	16	14.6	MJ/kg

These properties affect the operation of the HPS directly or indirectly, high moisture content in the biomass lead failure of the experiment. This is simply because lot energy is used in drying biomass. The temperature of the experiment were monitored, Figure 4 shows a failed experiment when we could not raise enough temperature to initiate the syn-gas generation because of high moisture in biomass.

4.2 Installation of the husk powered system

In order to manage materials and process flow on the case study site, a plant layout was drawn and below is the schematic layout of the husk powered system at the case site in Muduuma - Mpigi District as shown in Figure 1

There are three types of materials that are constantly flowing into and out of the HPS. These are the biofuels and the cooling water and the solid waste products. The cooling is in a closed circuit and the fuel is constantly being collected from the storage to the HPS.

The solid waste products however are only 12% so it just temporary stored next to gasifier and removed to its storage the following.

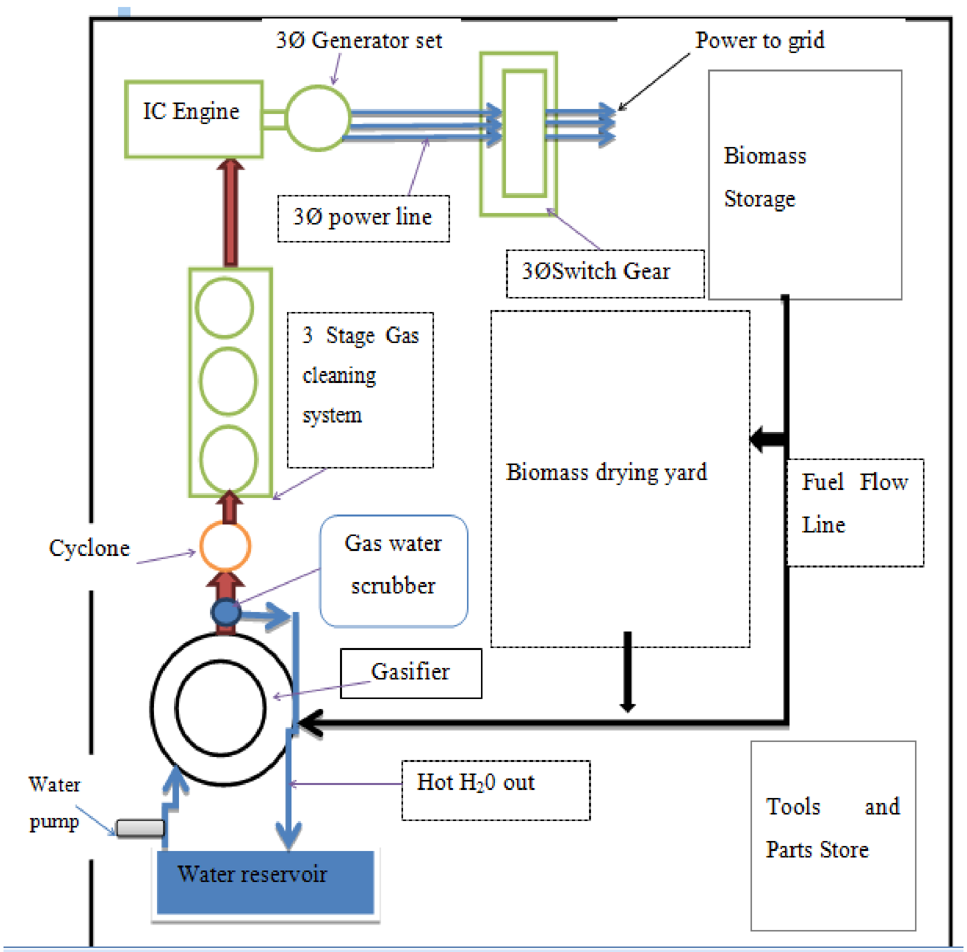


Figure 1: Layout of HPS at the case study site

Figure 1 show the plant layout that's was adopted at the case study site at Muduuma Parish, Mpigi district and was found to be convenient to the biomass flow.

4.3 Fuel flow rates

It was established that the husk powered system consumed an average of 30.22kg of maize cobs per hour with a standard deviation of 2.48kg and 25.24kg of coffee husks with a standard deviation of 0.9kg. The data is based on 22days of consecutive running of the HPS with two bio-fuels each observed for 11 days in each case.

The biomass consumption of the HPS gives the user an estimate of the minimum quantities of biomass which can be able sustain the system running. For example with maize cobs we need 7 tons of biomass a year to run the system for 6 hours a day. The advantage of the HPS is that the fuel is interchangeable with ease so practically 3.5 tons of maize cobs and 2.75 tons of coffee husks can sustain the system for a year with daily usage of 6hrs.

4.4 Output to the HPS

The power output measured was 34kW on all the 3 phases which was more than what the community could consume at the time of the study. This shows that the HPS is a viable solution to rural areas which raise 7 tons of biomass annually.

The mean power characteristics shown in Table 2 are within the expected range of values and therefore the power is safe for the appliances in Uganda.

Table 2: Power characteristics as measured by HT PQA 824 power quality analyser

Parameter	Recorded values (mean)	Expected values	Comments
Line voltage (V)	243	240	+/- 6% is acceptable
Phase Voltage (V)	422	415	+/- 6% is acceptable
Frequency (Hz)	50	50/60	It is within the range
Power output (kW)	34	32	The deviation is acceptable
Power Factor	0.858	0.8	Deviation acceptable

The results need to be discussed.

4.5 Start-up Time

This is the actual time from when you start firing the gasifier and the time when the internal combustion engine is started and so does the power generation. For this particular system the start-up time was seen to vary depending on the type of biomass being used. For this particular study two types of biomass were considered and the start-up times measured used were:

- The coffee husks took an average of **59**minutes
- The maize cobs took an average of **39**minutes

The maize cobs took shorter time because of the higher bed porosity compared to coffee husks. A study published by Yao Bin Yanga *et al*, 2005 that temperature in the gasifier increased with increase in bed porosity which was exhibited by the maize cobs as compared to coffee husks. The gasification temperature is therefore achieved faster when using maize cobs compared to coffee husks. This is critical in planning for the power delivery time to the grid.

4.6 Carbon-monoxide (CO) quantity in air around the HPS during operation

The CO in the air was monitored by Testo 950 Carbon monoxide monitor and also varied from start up to running of the system. During start up gas is sacked from the gasifier to the atmosphere which raises the carbon monoxide to 308.3ppm. Otherwise when the engine is turned on the carbon monoxide levels are only 82.8 ppm around the system

Figure 4: CO monitors reading at HPS start-up & at ambient running conditions

A plot of the CO levels against time from the time the system is started in Figure 5

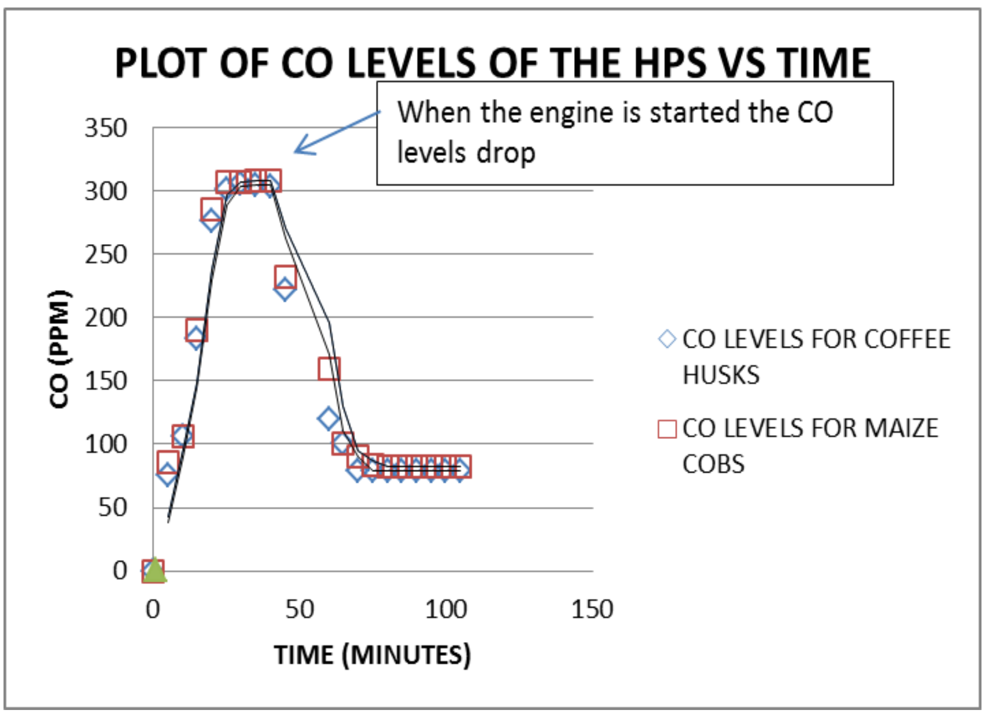


Figure 5: Plot of the CO emissions (PPM) against Time (Minutes)

The carbon-monoxide level of 308.3ppm around the HPS during starting is explained that during starting syn gas is extracted with lower concentration of burning gas species from the gasifier and exhaust in the atmosphere. This continues to build up CO levels until there are enough burning gas species in the synthetic gas to run the internal combustion engine hence the start of power generation.

Also during start-up, higher amount of smoke released when starting the system as shown in Figure 5 contributed to the CO level is higher levels.

Also the higher bed porosity of maize cobs allowing in higher level of oxygen generate relative higher amount of smoke compared to coffee husks as seen in Figure 5 which accounts for relatively higher levels of CO when using maize cobs.

Figure: 5 Smoke intensity during starting and when stability is achieved

Finally when the engine is turned on the CO levels are reduced to 82.8 ppm around the system which is still higher than the acceptable levels of 35ppm for human life (Matzen, July 1991). This so because all the gas sacked from the gasifier is burnt in the internal combustion engine and leakage on the system is reponsible for 82,8ppm detected.

4.7 Solid Waste Products

The main solid waste products from the system were bio-char, fine ash dust and tars which are semi liquid – semi solid. The bio char from the HPS forms about 12% for maize cobs and 10% for coffee husks of the total biomass fuel loaded into the gasifier shown in the figure below.

Figure 6: Bio-char from the HPS

The main solid waste products from the system were bio-char and fine ash dust repetition. The bio char contained a reasonable amount of energy and can be used as raw materials for charcoal briquettes. The heating value tests done on the bio-char shows that they have a retained energy value up to 23.8 MJ/Kg**.** This shows that it is a good source of raw materials for making charcoal briquettes.

4.8 Temperature Profile of the gasifier and syn gas

The temperatures of the whole system were monitored both internally and externally. The temperature profiles varied depending on the type biomass used with maize cobs registering the highest temperature of 900^{o}C at the reduction zone when the system was generating power. After the shutdown the temperature in other zones went up 1370^{o}C overnight as shown recorded temperature profile in the Figure 2

This was crucial to explain why we failed to generate power on some days, the temperature at the reduction failed to reach the required minimum of 500^{o}C.

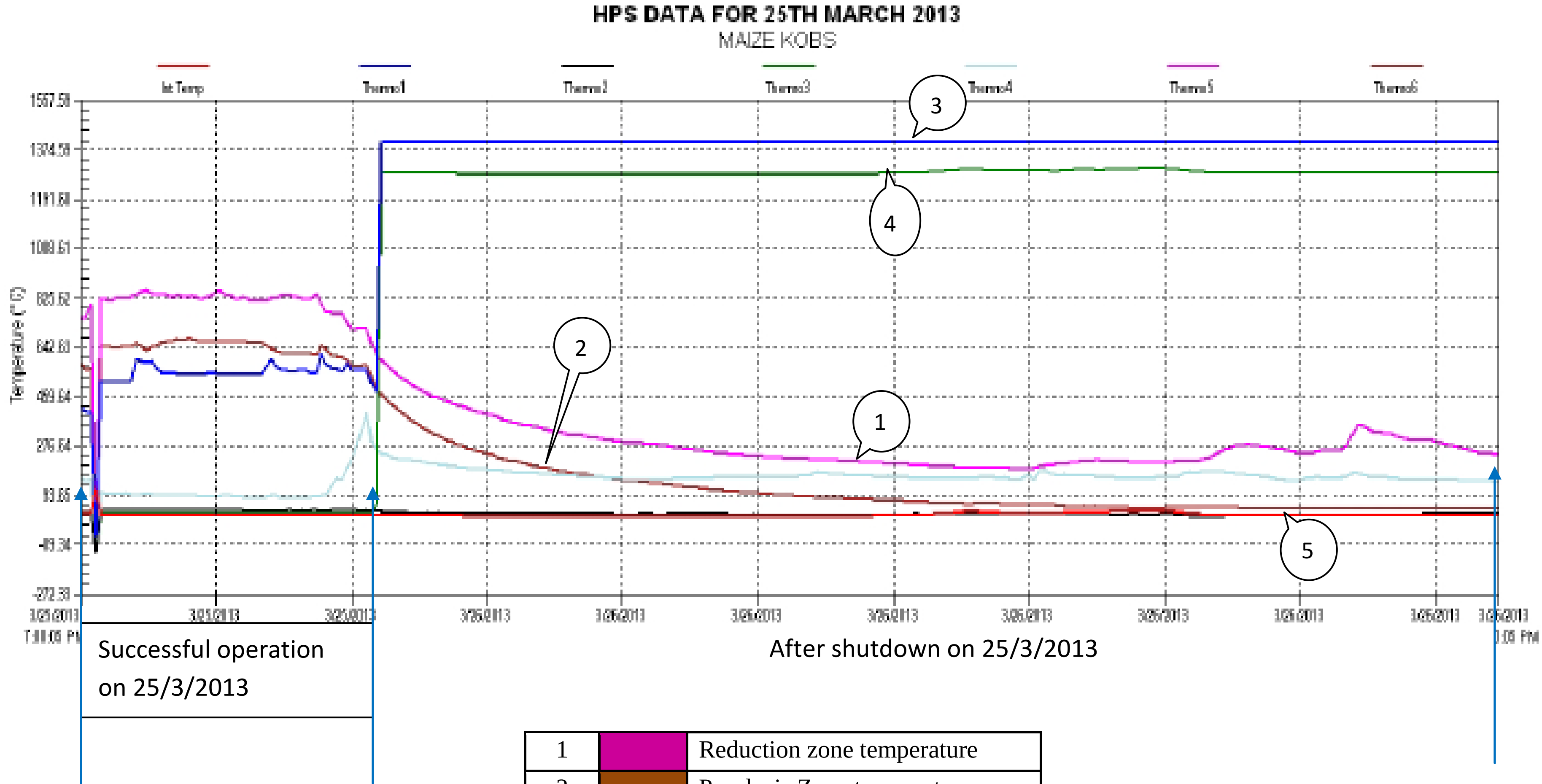
Also the temperature at the other zones rose up to 1370^{o}C after the gas flow to the engine was stopped on shutting down the system. The temperature rise could be explained by the basic reaction equations where some reactions are exothermic and others are endothermic. So when the engine is shut down, the syngas is stopped from leaving the gasifier the heat generated from the exothermic reactions accumulated inside hence the temperature rise from 858^{o}C to 1200^{o}C.

In a study published byKrigmont, (1999) showed the basic gasification reactions that occur in the reactor during gasification.

1) $C + O_2 \rightarrow CO_2$ -393 kJ/mol (exothermic
2) $C + H_2O \rightarrow CO + H2$ +131 kJ /mol (endothermic)
3) $C + CO_2 \rightarrow 2CO$ +172 kJ/mol (endothermic)
4) $C + 2H_2 \rightarrow CH4$ -74 kJ/mol (exothermic)
5) $CO + H_20 \rightarrow CO_2 + H_2$ -41 kJ/mol (exothermic)
6) $CO + 3H_2 \rightarrow CH_4 + H_20$ -205 kJ/mol (exothermic)

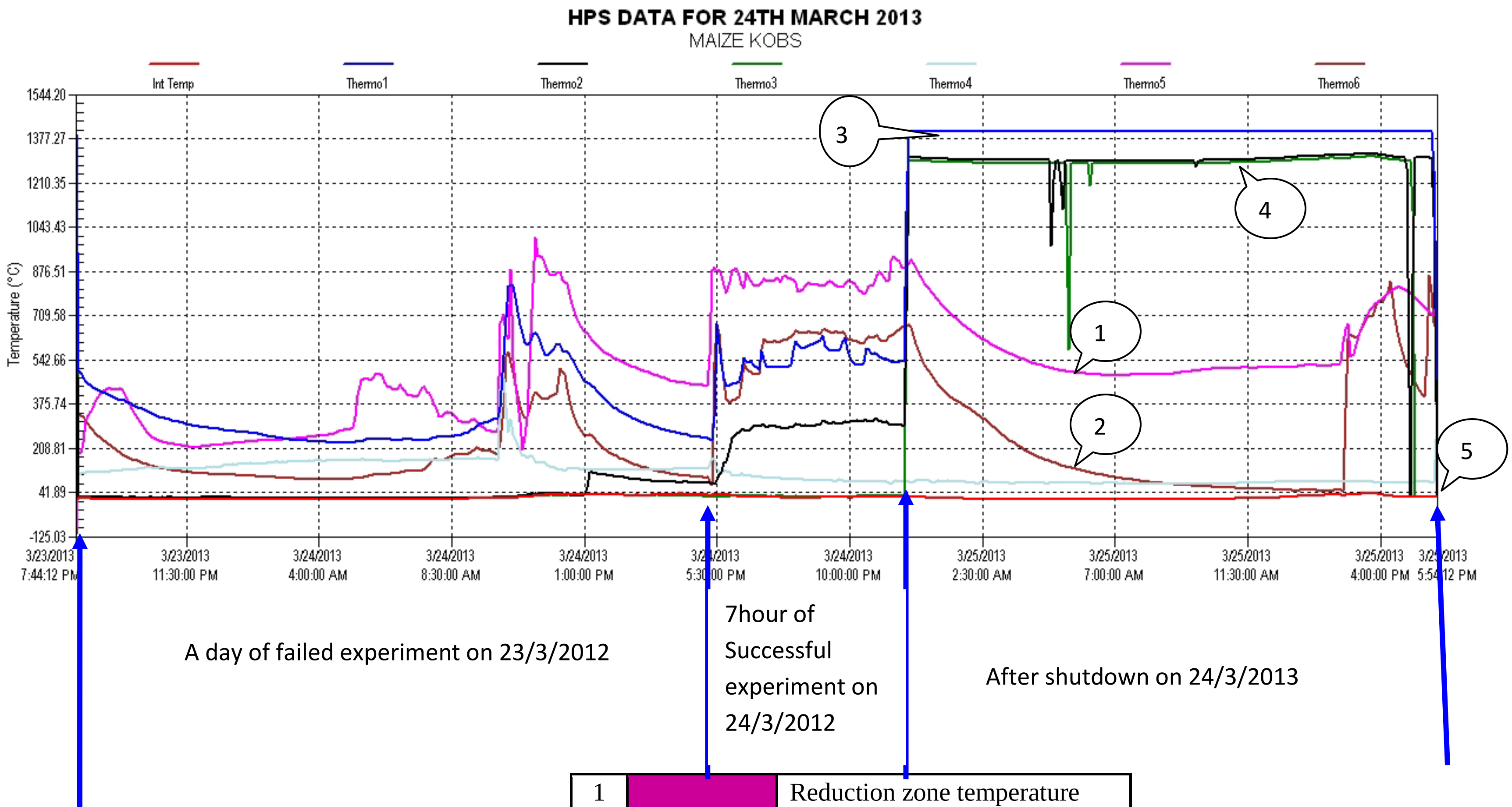
The total sum of the heat released and absorbed by the reacting species show a net in heat increase hence the temperature rise in the gasifier after the system is shutdown.

Figure 3 & 4 shows two different temperature profiles. Figure 3 show simply a successful experiment. The temperature at the reduction zone (tracked by pink colour graph labeled 1) raises to 828 ^{o}C , then at the end of experiment it comes down and temperature in the pyrolysis and drying zones goes up. This shift is caused by fire moving up in the fuel and ash foaming in the reduction zone. So we observe the temperature at the reduction zone is lowered while at the drying zone and in the fuels raises up to 1350oC and 1300 o C respectively



1		Reduction zone temperature
2		Pyrolysis Zone temperature
3		Drying zone temperature
4		Fuel temperature
5		Syn gas temperature

Figure 2: A days Temperature profile for the HPS



1		Reduction zone temperature
2		Pyrolysis Zone temperature
3		Drying zone temperature
4		Fuel temperature
5		Syn gas temperature

Figure 3: 2 days Temperature profile (a failed experiment and successful experiment)

4.9 The Unit Cost of Energy and the System Commercial Viability

In order to determine the unit cost of power generated, we created a business model based on actual costs incurred during the acquisition of the HPS and actual operating costs of the system at the case study site. The costs considered were: the initial capital costs of importing the HPS, the cost of the bio-fuels, paying the man power salary, cost of extending power to the consumers, and costs of licensing the system. The other costs that were not easily determined during the time of data collection were estimated using data from similar studies. All the costs were tabulated in Table 4-12.

Table 3: Cost parameters used in RETScreen software

Parameter	**Units**	**Values (maize cobs as fuel)**	**Values (coffee husks as fuel)**	**Data Source**
Initial capital investment of HPS	US$	81,480	81,480	REIC at CEDAT
Specific investment cost	US$kW^{-1}	2656.25	2656.25	Calculated
Annualized cost of operation and maintenance	US$	6,930	6,930	Calculated
Annualized cost of fuel	US$	755	4,217	Muduuna site
Discount rate	%	21	21	Uganda Commercial banks' lending rates

Results from the RETScreen software model were as follows

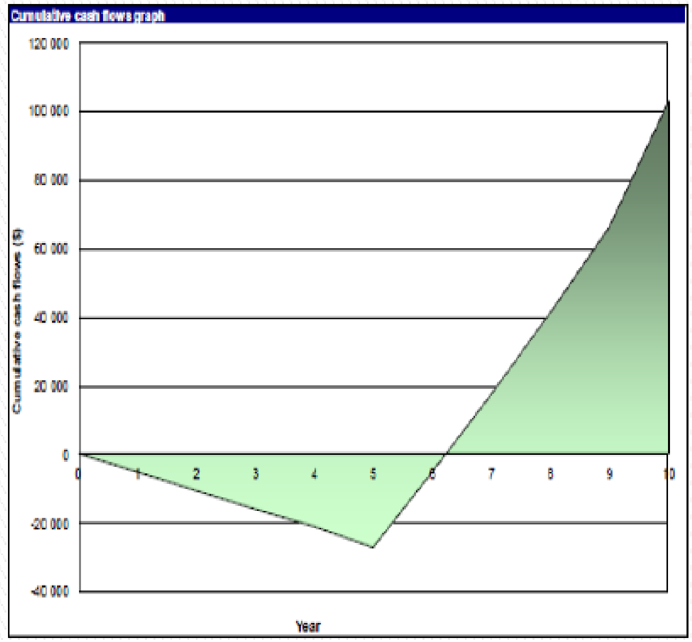
Using coffee husks as fuel which involved buying the fuel and transport costs

Table 4: Financial parameter rom the RETScreen model

Financial viability	Unit	Figure
Pre-tax IRR – equity	%	75.9
Pre-tax IRR – assets	%	9.0
After-tax IRR – equity	%	35.3
After-tax IRR – assets	%	2.5
Simple payback	Yr	3.4
Equity payback	Yr	immediate
Net Present Value (NPV)	$	63 939
Annual life cycle savings	$/yr	8 280
Debt service coverage		0.89
Energy production cost	$/MWhr	269.31

Table 5: Yearly Cash inflow

Yearly cash flows			
Year	Pre-tax	After-tax	Cumulative
#	$	$	$
0	0	0	0
1	-3 123	-5 407	-5 407
2	-1 970	-5 276	-10 683
3	-765	-5 251	-15 934
4	493	-5 361	-21 295
5	1 806	-5 640	-26 935
6	31 023	21 716	-5 219
7	32 453	22 717	17 498
8	33 944	23 761	41 259
9	35 500	24 850	66 109
10	37 122	37 122	103 230



Summary of the financial parameters from the RETScreen model

No-	Parameter	Coffee husks	Maize cobs
1	Simple payback period	3.4 years	3.3 years
2	Break even period	6.3 years	6.2 years
3	Net present value	63,939 USD	69 078 USD
4	Annual life cycle savings	8,946 USD	8 946 USD
5	Total annual savings and income	27 628 USD	27 628 USD
6	Total annual costs	31,856 USD	31 152 USD
7	Annual debit payments	27 847 USD	27 847 USD
8	Unit cost of energy per MWhr	269.31USD	259.28 USD

The unit cost of power was at US dollars 0.269/kWhr ie. UGx. 686/= which comparable to Umeme tariffs of UGx. 525/= + 18% VAT which is UGx. 619.5/= . Therefore if these systems are subsidized the rural Uganda can produce electricity from the biomass.

Also in the business sense with all capital borrowed you take 6.5 years to break even if all the electricity produced is sold and you supply power for 6 hours a day.

5.0 CONCLUSIONS

It was found possible to generate and sustain power supply to the rural areas with biomass (coffee husks and maize cobs) volumes up to 7 tons annually with electricity for 6 hours a day using the husk powered system (HPS). Therefore the HPS is recommended to the rural areas with sustainable volumes of biomass since the research established that the bio-fuels can be used inter-changeably in the husk powered system with ease.

The HPS can also be used as a money generating business and the unit cost of energy is comparable to that on the national grid.

6.0 ACKNOWLEDGEMENTS

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