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A small-scale gasifier-generator fueled by cocoa pod husk for rural communities in Ghana

Mark Worall[1*], Jo Darkwa[1], Eunice Adjei[2], John Calautit[1], Francis Kemausuor[2], Julius Ahiekpor[3], Nii Nelson[1], Robert Mokaya[4]
1 Department of Architecture and Built Environment, Faculty of Engineering, The University of Nottingham, University Park, Nottingham, NG7 2RD, UK , *email: worallmark@gmail.com (corresponding author)
2 College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
3 Centre for Energy, Environment and Sustainable Development, Kumasi, Ghana
4 School of Chemistry, The University of Nottingham, University Park, Nottingham, NG7 2RD, UK

ABSTRACT

Cocoa pod husk (CPH) has been investigated as a biofuel for use in a gasifier-electricity generator for cocoa farming communities in rural Ghana. CPH has embodied energy of approximately 17MJ/kg and so is a valuable energy source for bioenergy systems. A small-scale 5kWe CPH fueled gasifier-generator has been installed and its performance evaluated. At 4kWe, the system consumed approximately 11kg/h, supplying 27m^3/h of gas for the engine. Over 50% of the energy in the fuel was converted into combustible gas and 7.5% was converted into electricity. The gas engine efficiency was 25%, comparable to similar systems reported elsewhere. High moisture content reduced conversion efficiencies, but this can be easily overcome by employing enhanced drying techniques. Waste heat could be utilised to improve overall performance, so that 40-50% of the energy in the CPH can be put to useful purpose.

Keywords: Gasification, off-grid electricity, cocoa pod husk, bioenergy, sustainable energy

NONMENCLATURE

Abbreviations		
ASH	Ash content on dry basis	(%)
C	Carbon content on dry basis	(%)
H	hydrogen content on dry basis	(%)
FC	fixed carbon on dry basis	(%)
N	nitrogen content on dry basis	(%)
HHV	Higher heating value	(MJ/kg)
LHV	Lower heating value	(MJ/Nm^3)
O	Oxygen content on dry basis	(%)
S	Sulphur content on dry basis	(%)
VM	Volatile matter on dry basis	(%)

Symbols		
m_{fuel}	Mass consumption of CPH	(kg/s)
V_{gas}	Total producer gas volume flow	(Nm^3/s)
Q_{fuel}	Heat available from CPH	(kW)
Q_{gas}	Heat available from producer gas	(kW)
W_{elec}	Electrical power output	(kW)
y	individual gas volume fraction	(-)
η	efficiency	(%)
Subscripts		
CO	carbon monoxide	
CH_4	methane	
H_2	hydrogen	

1. INTRODUCTION

Ghana produces over 0.8 million tonnes of cocoa beans annually, over 20% of the world's cocoa bean production, and contributes around one sixth of Ghana's GDP [1]. Ghana has a poverty ratio of 23%, but this icreases four fold in rural areas, such as cocoa growing regions. Electrification rates are over 80%, but decline to around 16% in cocoa growing regions. The cocoa beans make up about one third of the whole fruit by weight, whilst the cocoa pod husk (CPH) makes up the remainder and is mainly discarded on the ground. Recent studies, including Adjin-Tetteh *et al* [2], reveal that CPH has a relatively high energy density of 17-18 MJ/Kg and has potential as a biofuel. Cocoa is cultivated over a wide geographical area in Ghana, using a variety of types, but it is not known how variable the quality and biofuel characteristics are. This paper reports on a novel use of a waste product of cocoa production that will ceate a

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local source of electricity generation. It is important to evaluate the CPH potential in all of the regions in order to assess its value as a biofuel.

Cocoa growing regions in Ghana are mainly in rural areas with poor access to grid electricity, and so use could be made of this waste product and valuable energy services could be provided to remote communities. Gasification is a technology that generates combustible gases such as hydrogen, methane, and carbon monoxide from hydrocarbons, in a reduced oxygen environment. The gases produced can be used directly for cooking or can be used in a gas engine to generate electricity. Evaluations of a small-scale gasifier-generators in Ghana have not been reported and so it is important that knowledge is gained of the process. In this study, a small scale (5kWe) system was developed in collaboration with Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana and a unit was procured and installed. The aim of this work is to characterize the CPH from various regions and investigate the performance of a small-scale CPH fueled gasifier-generator via field testing.

2. SMALL-SCALE GASIFIER-GENERATOR DESCRIPTION

Figure 1 shows an image of the 5kWe gasifier unit and figure 2 shows a simple schematic diagram of the system.

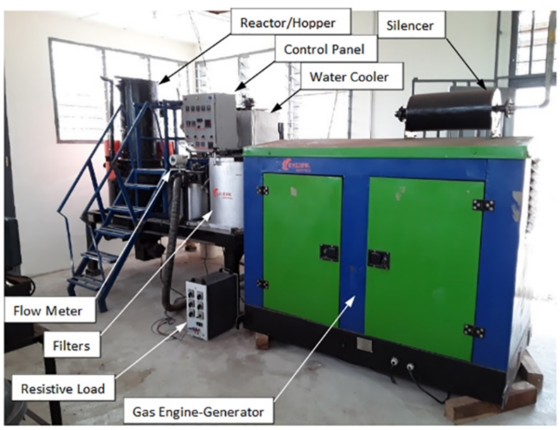

Figure 1. Labelled image of 5kWe gasifier-generator

The system consists of a reactor vessel and hopper 460mm in diameter and 800mm in height. A blower provides air to the reactor via an air valve and ignition pot. The hopper is filled with biomass and once gasification is initiated, the production gases are directed through a number of filters to remove particulates and tars that could damage the gas engine. A water cooler is provided to reduce the temperature of the producer gases. Following filtration, the producer gas enters a 4 stroke, 2 cylinder engine. The A.C. alternator produces 3 phase 415V at 50Hz. An electrical load is applied to the generator and the power output from the engine is measured.

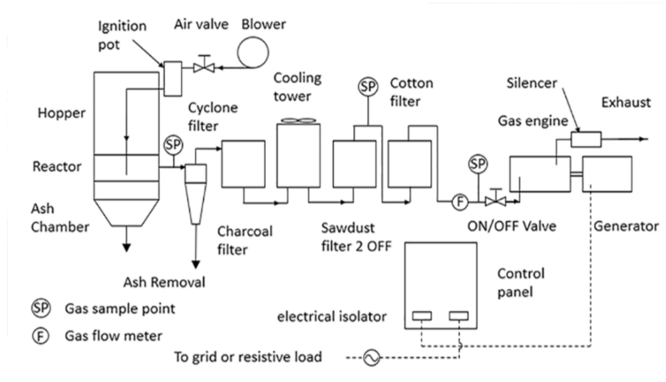

Figure 2. Schematic diagram of 5kWe gasifier-generator

A gas flow meter is sited between the final filter and the engine gas inlet, a gas sample point near to the gas inlet point is connected to a wall mounted gas monitor, measuring CO, CO_2, CH_4 and H_2. CPH mass consumption was determined by measuring the level of CPH at the start of the experiment, then checking the level at various times during the test. Temperatures at various points around the system were measured by K type thermocouples and electrical parameters, voltage, current, frequency were measured by a power meter sited on the control panel. The system was installed in a purpose-built plant room at the Engineering College, KNUST, in the Ashanti region followed by commissioning.

3. MATERIALS AND METHODS

3.1. CPH characterisation

Prior to installation of the gasifier-generator, CPH samples from four different cocoa plant types in Ashanti region, Amelonado, Amazonia, Trintario and Hybrid, were obtained and analysed to determine their chemical composition and heating values. Samples were sent to the University of Nottingham, UK, to determine their chemical characteristics. The CPH were broken into smaller pieces and were then reduced in size by a planetary ball mill and sieved to below 212µm. Chemical characterisation of the samples were then obtained using two analytical techniques. Proximate analysis (PA) was used to obtain volatile matter, fixed carbon and ash content using a fast characterization method [3]. A TA Instruments Q500 thermogravimetric analyser was used to determine the contents. Ultimate analysis (UA) was used to determine carbon, hydrogen, nitrogen, sulphur, and oxygen (by difference). A LECO CHN628 elemental analyser was used to determine the elements. Full description of the methodologies used to determine UA and PA is reported by Nelson, *et al*, [4].

The higher heating value (HHV) represents the calorific value of the fuel including contributions from moisture content. HHV can be determined from the composition of the CPH revealed by UA and PA, as follows;

For PA;

$$HHV = 0.3536FC + 0.1559VM - 0.0078ASH \quad (1)$$

For UA;

$$HHV = 0.3491C + 1.1783H + 0.105S - 0.1034O - 0.0151N - 0.0211ASH \quad (2)$$

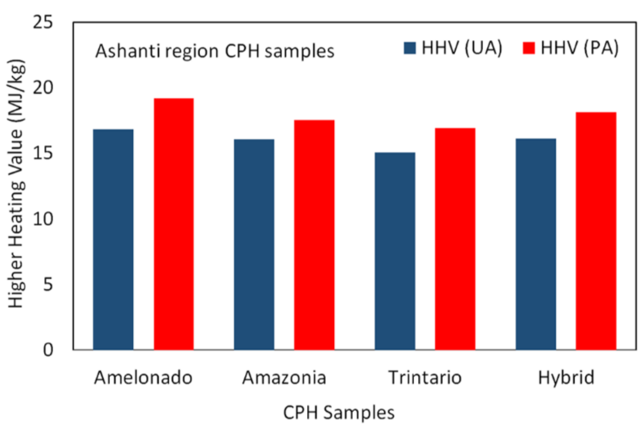

Figure 3. HHV for CPH samples from UA and PA

3.2. Gasifier-generator performance parameters

To determine the performance of the gasifier, energy transfers between the fuel, gasifier, the engine and electrical generator were calculated from the equations described below;

The energy available in the CPH including contributions from water is given by equation 3;

$$Q_{fuel}=m_{fuel}.HHV \quad (3)$$

The heat available from the combustible gases is determined from equation 4.

$$Q_{cg}=V_{gas}.(y_{CO}.LHV_{CO}+y_{CH4}.LHV_{CH4}+y_{H2}.LHV_{H2}) \quad (4)$$

The cold gas efficiency is defined as;

$$\eta_{cg}=Q_{cg}/Q_{fuel} \quad (5)$$

The overall efficiency is defined as;

$$\eta_{ov}=W_{elec}/Q_{fuel} \quad (6)$$

The conversion efficiency from cold gas to electrical power is defined as;

$$\eta_{conv}=W_{elec}/Q_{cg} \quad (7)$$

4. RESULTS

4.1 CPH characterization

Higher heating values (HHV) were determined from UA and PA and are presented in figure 3.

The average HHV was 16.0MJ/kg and 17.9MJ/kg for UA and PA, respectively. The average chemical characteristics of the CPH from UA and PA are reported in Table 1.

Table 1. Comparison of UA and PA results

	VM	FC	ASH	C	H	N	O	HHV (UA)	HHV (PA)
CPH*	**67.3**	**22.8**	**10.07**	**42.4**	**5.7**	**1.4**	**50.5**	**16.0**	**18.5**
[5]	62.3	36.1	1.6	50.0	6.0	0.7	43.3	16.6	
[5]	68.8	27.0	4.1	43.8	5.2	0.6	50.3	15.4	
[5]	73.7	12.0	14.3	43.5	5.1	0.5	50.8	16.7	
[6]	68.8	23.2	8.1	48.8	7.9	1.9	39.9	18.9	

***Average values from this study**

4.2. Commissioning tests

The hopper was filled with CPH and the gasification process started. Once clean gases were produced, the engine was operated at zero load for about 60 minutes and then an electrical load was applied to the generator using the resistive load. The engine is rated at 5kWe maximum over short periods, but continuous maximum load of 4kWe. The load was set to 5kWe for a few minutes to check that it could produce the maximum stated output but was then reduced to 4kWe for the remainder of the test. At zero-load, CPH consumption was approximately 7kg/h, at 5kW, consumption was 14kg/h and at 4kW consumption was 11.5kg/h.

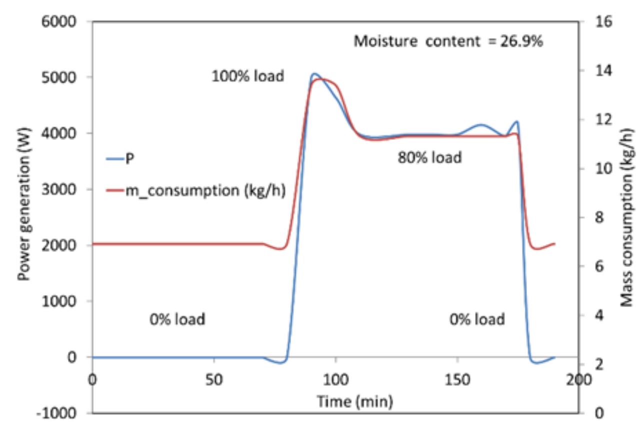

Figure 4. Variation in power and mass consumption

Table 2 shows results from sampling of the producer gases.

Table 2. Producer gas sampling

	CO (vol%)	CO_2 (vol%)	H_2 (vol%)	CH_4 (vol%)
Sample 1	12.1	17.2	12.0	4.9
Sample 2	13.8	16.5	14.0	3.8
Sample 3	14.8	15.4	10.4	2.8
average	13.6	16.3	12.1	3.8
[7]	19.5	15.0	19.0	0.0

Table 3 shows the values used for calculating heat transfers and efficiencies. The values for HHV, LHV_{CO}, LHV_{CH4} and LHV_{H2} used in equations 3 and 4, were taken as 16.9MJ/kg, 11.6MJ/Nm^3, 32.8MJ/Nm^3 and 9.9MJ/Nm^3, respectively.

Table 3. Gasifier efficiencies

	m_{fuel}	V_{gas}	Q_{fuel}	Q_{gas}	W_{elec}	η_{cg}	η_{ov}	η_{conv}
	kg/h	Nm^3/h	kW	kW	kW	%	%	%
CPH*	**6.9**	**14.4**	**32.6**	**16.1**	**0.0**	**49.4**	**-**	**-**
CPH*	**11.3**	**26.6**	**53.4**	**32.8**	**4.0**	**55.7**	**7.5**	**25.3**
[7]	4.7	9.9	24.6	14.7		60		
[7]	5.7	12.4	29.7	18.9		64		
[7]	7.5	14.7	39.2	23.2		59		
[7]	5	12.5	30	18	3.2	60	10.7	18

*** Results from this study**

Table 3 also shows results reported by Barro [7] on experiments on a small-scale downdraft gasifier and engine. It should be noted that the engine was tested using different gas compositions and not from gasifier production gases and were reported as indicative only. We are reporting these as indicative of engine outputs with similar producer gas and engine capacities. Table 3 shows that for the zero-load period, the heat available from the CPH and the producer gas were 32.6kW and 16.1kW, respectively, giving a cold gas efficiency of 49.4%. At 80% (4kWe) load, the heat available from the CPH and the producer gas were 53.4kW and 29.7kW, respectively, giving a cold gas efficiency of 55.7% and overall conversion efficiency of 7.5%. Cold gas conversion efficiency was 25.3%. Barro [7] reported brake thermal efficiency of 18% for producer gas equivalent to a 30kW gasifier with a feed 5kg/h and producer gas flow of 12.5m^3/h. This gives overall efficiency of approximately 10%, which is comparable to our gasifier-generator. Moisture content in the tests we carried out was 26.9%, which is high in comparison with results reported by Barro [7], which was approximately 7.5%. Options for improving conversion efficiency include reducing moisture content by extended drying times, using solar driers, using exhaust from the engine to dry raw samples, using pellets instead of roughly crushed feedstock. Overall system efficiency could be improved by utilising some of the waste heat. Waste heat can be used for space heating, cooling, water purification and desalination, so overall efficiencies could increase to 40-50%.

5. CONCLUSIONS

This paper has shown that across all cocoa types, CPH has embodied energy of 15MJ/kg to 18MJ/kg and so is a valuable energy source for bioenergy systems. A small-scale bioenergy system generated 4kWe, whilst consuming 11kg/h of CPH, supplying 27m^3/h of gas for the engine. Over 50% of the chemical energy in the fuel was converted into combustible gas and 7.5% was converted into electricity. This was comparable with other similar systems. Over 25% of the combustible gas was converted into electricity. The overall conversion efficiency was low but could be improved by reducing moisture content. Waste heat could be utilised to improve overall performance, so that 40-50% of the energy in the CPH can be put to useful purpose.

Future work will evaluate long-term performance, rural community engagement, environmental and economic lifecycle costs and benefits, and the roll-out of sustainable electricity production to cocoa farming communities.

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