Evaluating selected inedible fibrous crop residues as feedstock for gasification

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Abstract

Four feedstocks derived from different sources of fibrous biomass were evaluated in a down-draught gasifier. The fibrous wastes were coconut shell-husk, woody stems of cassava and mulberry, and the branches from the ornamental tree, *Cassia stamea*.. The materials were chopped (2-4 cm length) and sun-dried to 20% or less moisture content. Three tests were done with each feedstock.

The density of the feedstock was highest for the *Cassia stamea* and lowest for cassava and coconut, with an intermediate value for the mulberry. Despite these differences in feedstock density, there were no differences among sources of feedstock in the operating parameters of the gasifier (yield and conversion of feedstock to electricity, and energetic efficiency). The conversion of feedstock to electricity was in the range of 1.11 to 1.23 (kg dry biomass/kwh); energetic efficiency (MJ of electricity/MJ of biomass) was in the range of 0.19 to 0.22, compared with 0.29 for a diesel engine-generator.

Fibrous woody residues in the form of coconut husks and stems of cassava, mulberry and *Cassia stamea* are efficient and effective sources of feedstock in a downdraft gasifier.

Key words: Cassia stamea, cassava, coconut, electricity, gasification, mulberry, renewable energy, residues.

1. Introduction

The population in the world increases very fast, especially in the developing countries. At the same time, there are two major world trends which threaten to change dramatically the lives of all who live on this planet. Supplies of fossil fuel which have been the source of economic development during the past century are depleting faster than had previously been supposed (Schempf 2004). At the same time global warming is predicted to lead to temperature increases of between 2 and 5 ºC by the year 2050, if fossil fuels continue to be used at the present rates. It is imperative therefore that all alternatives for producing renewable non-polluting energy be promoted.

There are abundant resources of biomass produced by photosynthesis, especially in tropical latitudes, much of which is poorly utilized. Fibrous woody biomass can be obtained in several ways:

- by growing trees for lumber and pruning the lateral branches
- from the pruning of trees grown for ornamental and / or shade purposes in the cities
- from agricultural/forestry residues
- from stems of trees and shrubs grown as sources of protein (from the leaves) for live stock

Gasification is a process for deriving energy from fibrous biomass and it appears to have many environment and socio-economic advantages such as:

- Employment is generated in the growing, harvesting and processing of the biomass
- Gasification produces a mixture of gases (hydrogen, carbon monoxide, nitrogen and carbon dioxide)

- Combustion (in an internal combustion engine or turbine) of the hydrogen yields water, and carbon monoxide is oxidised to carbon dioxide; these final products (water and carbon monoxide) are substrates for synthesis of carbohydrate through photosynthesis
- The process can be de-centralized as units are available with capacities between 4 and 500KW

The purpose of this study was to evaluate the efficiency and effectiveness of fibrous residue as feedstock in gasification.

2. Materials and Methods

2.1 Location

The experiment was done in the farm of the Center for Livestock and Agriculture Development (CelAgrid), located about 28 km from the capital city of Phnom Penh.

2.2 Equipment

The gasifier was imported from Ankur Scientific Energy Technology Pvt. Ltd, India. The gasifier (WBG model) is specifically designed for woody feedstock. The Ankur biomass gasifier model “Ankur GAS-9” consists of a biomass gasifier (model WBG-15) connected to a 25 HP Field Marshal gas engine coupled with a 15 KVA alternator (duly modified to operate in 100% producer gas mode) to give a gross output of about 9 kWe with a net output of 8 kWe. The whole system is divided into three main units, i)-gasifier, ii)-filter and iii)-engine. The basic features of the system are (according to the direction of the gas flow):

- **Gasifier** divided into 3 sections: hopper, reaction unit and ash collector. The hopper stores the feedstock (capacity about 140 kg of wood). It consists of *drying zone* and *pyrolysis zone*. The reaction zone has a *combustion zone* and *reduction zone*. The ash section is the bottom part for storing ash.
- **Venturi scrubber** is a tool for blowing the air into gasifier system using a current of water driven by a small pump.
- **Cyclone separator** is the place for cooling, cleaning and separating the gas from the water
- **Fine filter** is a container, filled with saw dusk for capturing dust.
- **Safety filter** is a container with cloth 1x1 mm mesh sieve. The gas emerging from these filters is extremely pure and clean, suitable for burning in an internal combustible engine.
- **Flare** is a tube in a vertical plane for testing the gas quality by burning before the engine starts
- **Gas control valve** determines the amount of gas going into the engine according to the needs of the engine
- **Air filter** for cleaning air and mixing with the gas prior to entering the ignition zone of the engine
- **Engine** 25 HP Field Marshal model drives a 15 KVA generator for electricity
- **Exhaust pipe** is hot (about 250^{o} C) and used for drying wet feedstock.

2.3 Experimental design

The four treatments were different sources of fibrous biomass:

- Cassava woody stem (CWS) [Figure 1]
- Mulberry stem (MS) [Figure 3]
- Branches from the ornamental tree *Cassia stamea* (CS) [Figure 5]
- Coconut husk (CH) [Figure 7]

Figure 1: Cassava stems chopped

Figure 2: Cassava root cultivation

Figure 3: Mulberry stems chopped

Figure 4: Mulberry leaf cultivation

Figure 5: *Cassia stamea* chopped

Figure 6: *Cassia stamea* for shade

Figure 7: Coconut husks chopped

Figure 8: Coconut fruit cultivation

	
Figure 9: Cassava stems were burnt on the field after harvest	**Figure 10**: Slight use of cassava stems by farmers

	
Figure 11: Potential use of cassava leaf (feed) and stem (energy)	**Figure 12**: Potential of coconut husk in energy sector

Each source of fibrous biomass was evaluated as feedstock in the gasifier on three separate occasions. It was planned originally to include sugar cane bagasse in the test, but this had to be abandoned due to difficulties in preparing the material in a satisfactory manner for burning in the gasifier.

2.4 Experimental procedure

The coconut husk was collected from the waste at the point of sale of the coconut juice in Phnom Penh city. The cassava woody stem (CWS) was obtained from a cassava plantation in CelAgrid that was being harvested to provide foliage for pigs and goats. Mulberry stems were from a plantation in CelAgrid grown as a source of foliage for pigs, and harvested at 8 week intervals. The branches (CS) were from *Cassia stamea* trees planted in the fence lines between plots and in the perimeter fence in CelAgrid.

2.5 Biomass processing

The different sources of biomass were cut into small pieces, of about 2 to 4 cm length and 1 to 3 cm width, and then sun-dried in the open air until the moisture content was less than 20%. Small branches (diameter below 2 cm) were cut by hand with a knife. Larger branches (diameter >2 cm) were cut by an electrical woody biomass cutter.

2.6 Operation of the gasifier

The first step was to fill the reduction zone with charcoal (about 20 kg) with a particle size of 2 to 3 cm. A weighed quantity (about 40 kg) of feedstock was then added to the hopper. Air was forced through the gasifier by the action of the water pump and the venturi valve. The charcoal inside the gasifier was then lit with a flare and after 5 to 10 minutes, the producer gas was tested for quality. When the gas was seen to burn with a colourless flame and the flow was constant, the engine was started and the parameters of the system were recorded until all the feedstock was used up and the engine halted. The system was allowed to cool, after which the hopper was removed and the quantities of residual feedstock and charcoal were measured. The quantity of char (mixture of charcoal and ash) removed from the grate was weighed. The following day the procedure was repeated with another source of feedstock.

2.7 Measurements

The moisture content of the biomass was determined with an electronic meter with precision of ±1 unit. Bulk density (kg/m^3) was measured by putting the cut pieces of feedstock in a wooden box (previously weighed) of known volume. The box was then weighed to determine the weight of each biomass.

2.8 Statistical model and calculations

The energetic efficiency of the gasifier was calculated on the basis of the assumptions that dry wood has a gross energy content of 15 MJ and that 1 kwh of electricity is the equivalent of 3.75 MJ of energy. The data were analysed using the General Linear Model of the ANOVA software from Minitab (2000), Version 13.31. Sources of variation in the model were sources of biomass and error.

3. Results

The density of the feedstock was highest for the *Cassia stamea* and lowest for cassava and coconut, with an intermediate value for the mulberry (Table 1). Despite these differences in feedstock density, there were no differences among sources of feedstock in yield (Figure 13) and conversion of feedstock to electricity and energetic efficiency.

Table 1: Mean values for gasifier characteristics using coconut shells-husks, cassava stems, mulberry stems and branches of *Cassia stamea* as feedstock

	Cassia	Cassava	Mulberry	Coconut	SEM	Prob.
Biomass DM, kg/test						
Initial	36.7	32.3	33.7	34.4	1.3	0.21
Final	4.93	1.90	0.00	3.07	2.19	0.49
Consumption	36.9	35.1	40.0	36.4	2.9	0.69
Moisture, %	14.0	13.3	15.7	14.0	1.4	0.69
Density, g/litre	348a	97.0c	273b	128c	10.4	0.001
Duration, hr	3.91	3.67	4.09	4.02	0.328	0.810
Output, kwh	27.4	25.7	28.7	28.2	2.29	0.810
Conversion*	1.23	1.18	1.18	1.11	0.044	0.42
Yield, kwh/kg DM biomass	0.813	0.848	0.850	0.903	0.032	0.400
Efficiency#	0.187	0.204	0.204	0.217	0.0082	0.170
Char, g/kg biomass DM	109	128	109	137	16.5	0.58

** kg dry biomass/kwh; # Assumes 15 MJ/kg biomass DM and 3.6 MJ/kwh of electricity*
abc Means in the same row without common letter are different at P<0.95

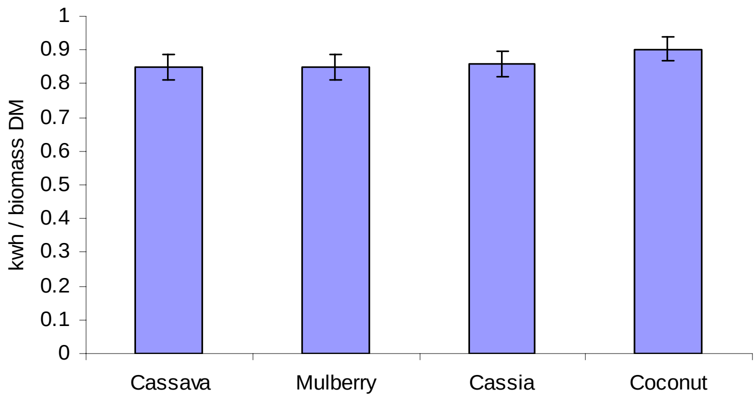

Figure 13. Yield of electricity (kwh) from woody biomass derived from coconut shells, mulberry stems, cassava stems and branches of *Cassia stamea*

4. Discussion

The sources of substrate used in this experiment apparently have not previously been studied as feedstock for gasification. According to Ankur (2005), the average value for conversion of wood to electrical energy is of the order of 1.2 kg dry biomass for 1 kwh. This is similar to the data recorded in the present experiment. The conversion of coconut husk (1.11 kg/kwh) is better than reported by Rajshekar, (1999) which was 1.5 kg/kwh. The difference might be the way of processing and the type of gasifier.

The overall energetic efficiency with different feed stocks (expressed as MJ of electrical energy per MJ of biomass) was in the range of 0.19 (Cassia) to 0.22 (coconut shells-husks). The comparative figure for the efficiency of producing electricity from diesel oil in an internal combustion engine-generator (3.14 kwh/litre of diesel) is some 35% higher (about 0.29).

5. Conclusions

- Fibrous woody residues in the form of coconut husks and stems of cassava, mulberry and *Cassia stamea* are efficient and effective sources of feedstock in a gasifier.
- The rates of conversion and efficiency values for the four selected feedstocks (coconut husk, cassava stem, mulberry and cassia stamea) were similar.
- The overall energetic efficiency (expressed as MJ of electrical energy per MJ of biomass) was in the range of 0.19 (Cassia) to 0.22 (coconut shells-husks)

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