ENERGY PRODUCTION FROM THERMAL GASIFICATION OF SELECTED MUNICIPAL SOLID WASTES FROM THIKA MUNICIPALITY OF KIAMBU COUNTY, KENYA

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Abstract
Thermal gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. The waste dumped in the dumpsite consists of plastic papers, organic waste, textiles, rubber, rice husks, maize combs among others. The study aimed to determine the energy production potential from conversion of solid wastes to energy resources using thermal gasification. Selected carbonaceous waste such as rice husks, maize combs and sawdust were gasified in a fixed bed updraft gasifier to obtain synthetic gas (syngas) and carbonized residues. Samples of the syngas were collected in evacuated clean air tight plastic containers. 1 ml of the sample was injected into a gas chromatograph (GC-TCD) and the CO_2, CO, CH_4, H_2, N_2, and O_2 concentrations were determined using a thermal conductivity detector (TCD). The study found that 25Kg of rice husks fed to the gasifier, produced 580±4.2 m^3 of syngas, with sawdust producing 480±2.8 m^3 and maize combs producing 420±3.1 m^3 for the same weight of feedstock. Syngas from rice husks was found to contain 9.81±0.99% CH_4, 28.55±0.99% CO, 12.59±0.99% CO_2 7.44±0.99% N_2, 8.34±0.99% O_2 and 34.06±1%H_2 while that from sawdust gave 12.06±1.13% CH_4, 34.34±1.13% CO, 8.24±1.1% CO_2 5.11±1.1% N_2, 5.96±1.13% O_2 and 34.4±1.1% H_2. Maize cobs gave syngas of 24.74±2.70CH_4, 27.90±1.64CO, 9.99±1.52CO_2, 7.44±0.11N_2, 11.97±0.58O_2 and 30.32±0.74O_2.
The calorific value of syngas from sawdust was 16.17 MJ/m^3while rice husks had 13.18 MJ/m^3 with maize combs giving 12.1 MJ/m^3. The higher content of CH_4 and CO in sawdust contributes to its higher calorific value than rice husks. The results obtained in this study are an indication that there is a high potential of energy production from carbonaceous waste.

Key words: Solid waste, gasification, waste to energy, rice husks, saw dust, maize combs, syngas

1.0 Introduction
Gasification or controlled partial oxidation of a carbonaceous material is achieved by supplying less oxygen than the stoichiometric requirement for complete combustion. Air (or oxygen in some applications) is used as a gasification agent, and the air factor is generally 20% - 40% of the amount of air needed for the combustion (Daniela *et al*., 2002). As a central process between combustion (thermal decomposition with excess oxygen) and pyrolysis (thermal decomposition in the absence of oxygen), it proceeds at temperatures ranging between 600°C and 800°C. Depending upon the process type and operating conditions, low- or medium-value producer gas, which is a combination of combustible and non-combustible gases, is created (Doherty *et al*.,2009; Jaojaruek *et al*.,2011). The main feature of this technology is its ability to produce a reliable, high-quality synthesis gas (syngas) product that can be used for energy production. The primary product of this gaseous mixture is carbon monoxide and hydrogen, with minor percentages of gaseous hydrocarbons also formed**.** The thermo chemical conversion changes the chemical structure of the biomass by means of high temperature conditions. The gasification agent allows the feedstock to be quickly converted into gas by means of different heterogeneous reactions (Kathirvale *et al*., 2004; Narvaez *et al.,* 2004; Singh *et al*., 2011). The combustible gas contains CO_2, CO, H_2, CH_4, H_2O, trace amounts of higher hydrocarbons, inert gases present in the gasification agent, various contaminants such as small char particles, ash and tars (Themelis *et al*., 2003).

2.0 Materials and Methods
2.1 Area of Study
This study was carried out in Thika municipality of Kiambu County. The municipality lies between latitudes 3°53′ and 1°45′ south of Equator and longitudes 36°35′ and 37°25′ east (Robinson *et al*., 2005). Kang'oki dumpsite is the major dumpsite in the municipality. This is the site where this study was carried out.

2.2 Sample Collection

Solid wastes at the Kang'oki dumpsite were characterized to indentify their composition. Site-specific study methodology was used, where sampling, sorting, and weighing the individual components of the waste stream was done. This methodology is useful in defining a local waste stream, especially if large numbers of samples are taken over several occasions (ASTM, 2003). Municipal solid wastes that were characterized came from residential, commercial, institutional, or industrial sources. From the characterized waste some carbonaceous waste which include – rice husks, maize combs and saw dust were selected which formed the feedstock for gasification.

2.3 Sample Treatment

The selected samples were dried by spreading them on sunlight to reduce the moisture content. Samples of this waste were taken and tested to monitor the moisture levels before gasification.

2.4 Data Collection

The data that was obtained from gasification and from laboratory analysis was tabulated for further analysis.

2.4.1 Thermal Gasification of Selected Waste

After characterization of the waste, the carbonaceous waste was separated from the other combustible waste. Rice husks, maize combs and sawdust were gasified in a locally assembled fixed bed updraft gasifier in the Institute of Energy and Environmental Technology of Jomo Kenyatta University of Agriculture and Technology(JKUAT). The gasifier is a small unit consisting of a 40 cm diameter and 200cm height reactor equipped with an electric blower to provide the air needed in gasifying the feedstock. The gasifier was feed with 25 kg of rice husk at the beginning of the experiment and char was removed from beneath the gasifier at the char box. The gas coming out of the reactor is conditioned by allowing it to pass through the gas-cleaning devices which consisted of wet scrubbers, tar condenser cyclone, and a series of two wood shavings packed filters. Fig. 1 shows the gasifier used to undertake this experiment.

Fig. 1: The gasifier equipment used in the test and the temperature monitoring meter

2.4.2 Compositional Analysis of Syngas

The non-condensable gases were tested according to the American Standard Test method ASTM D2504-88(1998) in the JKUAT food science laboratory using a gas chromatograph thermal conductivity detector (GC-TDC) and gas chromatography flame ionization detector (GC-FID). An isocratic mode was used since a constant temperature was maintained throughout the operation. The detector initial and final temperature was set as 150^oC. The column was set and maintained constant throughout the operation time, with an initial temperature of 120^oC. Sufficient time of 1 hour was allowed for temperature stabilization before the start of analysis.

Samples of the syngas were collected from the pipeline connected to the reactor into evacuated clean plastic containers. 1 ml of the sample was injected into a gas chromatograph (GC-TCD) and the CO_2, CO, CH_4, H_2, N_2, and O_2 concentrations were determined using a TCD. Calibration gases were prepared in helium by marking the appropriate dilutions and a standard curve for the concentration versus peak area values was obtained for each standard gas. Sample concentrations were obtained from the appropriate calibration curves. For compound identification, standard gases for each gas sample were used. The operational conditions were optimized and sufficient time of not less than 1hr was allowed for temperature stabilization so as to provide a good resolution and minimum analysis time. Initial instrument calibration was carried out. Analysis parameters used are as shown in the table 2.1.

Table 2.1 operational conditions and analysis parameters

Column Width 6	**Slope 50**
Drift 0	MIN. AREA 100
T.DBL 0	STOP. Time 6
Attenuation factor 4	Speed 10
Method 41	Format 0

Typical Chromatograms for this analysis are shown in figure 2.

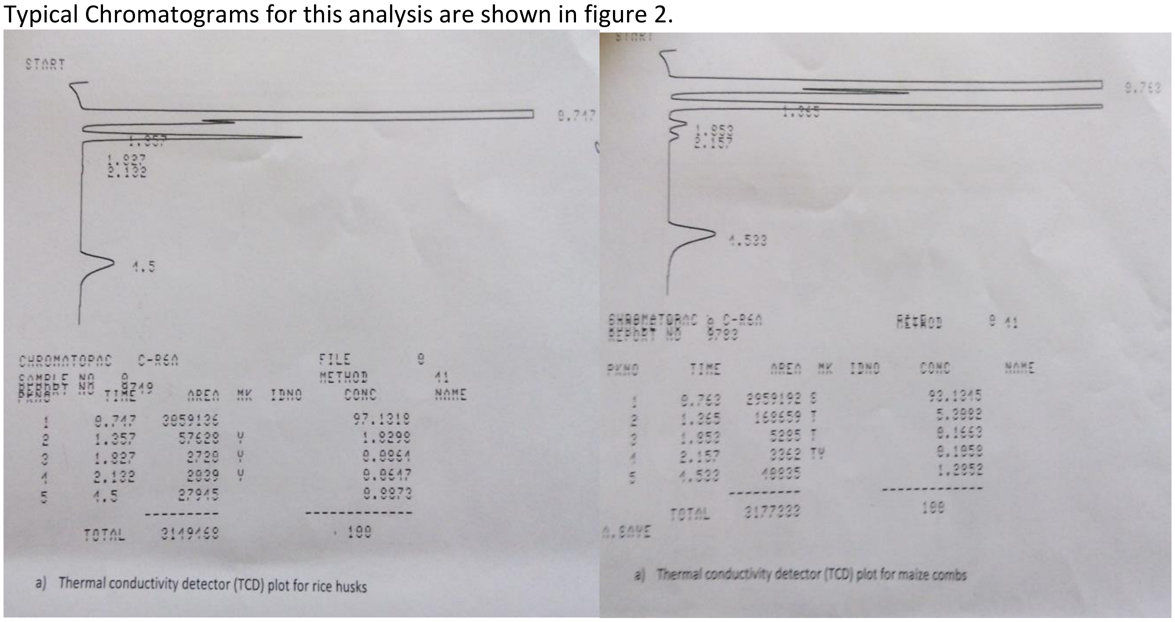

Fig. 2: Chromatograms of the gas analysis, using Gas chromatograph thermal conductivity detector (GC-TDC)

2.5 Data Analysis

The data generated from the experiments was coded and tabulated for analysis. Analysis was through the use of descriptive statistics and correlation. The data was summarized into frequencies and percentages and presented in tables and figures. Frequencies and percentages were adopted to present, discuss and interpret the findings obtained.

3.0 Results and Discussion

3.1 Gasification of Selected Municipal Solid Waste

The gasification experiment was operated at specified parameters and it yielded the results shown in table 3.1.

Table 3.1: Operation parameters and results for the gasification tests

Type of feedstock - Rice husks	Measured value		
	Rice husks	Sawdust	Maize combs
Total operation time (min)	150	180	120
Moisture content(% wet basis)	10	12	10
Initial weight of feed (kg)	25	25	25
Feed in air (m^3/min)	8.2	8.2	8.2
Average reduction zone temperature (at the bottom) (°C)	510±2.3	410±2.1	420±3.1

Average drying zone temperature (at the top) (°C)	222±1.9	222±1.7	220±2.1
Estimated gas yield (m^3)	580±4.2	480±2.8	420±3.1
Average calorific value of syngas (MJ/Nm^3)	13.18 ±0.12	16.17±0.23	12.1±0.18

When the gasifier was fired it started producing gas at a temperature of 67^0C at the top (drying zone). This temperature continued rising as the thermal decomposition increased and attained about 210^0C in 30 minutes. During this time about $174m^3$ of producer gas was produced. The gas was fueled to drive an engine. The engine ran at a variable speed of between 1852rpm to a maximum of 3856 rpm. Shaft speed of the engine was measured using a digital tachometer as shown in figure 3. The engine is entirely fueled by the gas generated, except at the start-up and at the end of the operation. It took the gasifier between two and three hours to decompose the various feedstock used.

Fig 3: measuring the shaft speed of a gas driven engine using a digital tachometer.

The syngas generated was analyzed to establish its composition. The composition of the gas is as shown in the table 2.

Table 2: Syngas composition of selected waste

Parameters measured	Syngas from rice husk Average conc (ppb)	Abundance %	Syngas from sawdust Average conc (ppb)	Abundance %	Syngas from maize combs Average conc (ppb)	Abundance %
CH_4	9.18±0.31	9.81±0.99	13.60±1.76	12.06±1.13	24.74±2.70	22.02±1.10
CO	28.84±0.25	28.55±0.99	38.72±3.06	34.34±1.13	27.90±1.64	24.83±1.12
CO_2	12.61±3.55	12.59±0.99	9.29±4.53	8.24±1.10	9.99±1.52	8.89±1.12
N_2	7.51±0.15	7.44±0.99	5.76±0.76	5.11±1.10	7.44±0.11	6.62±1.10
O_2	8.22±0.25	8.34±0.99	6.72±0.74	5.96±1.13	11.97±0.58	10.65±1.12
H_2	34.4±0.12	34.06±0.99	38.79	34.40±1.10	30.32±0.74	30.32±1.12

3.3 Estimation of Energy Derived From Gasification of MSW

While using saw dust the average volume of gas generated was $480m^3$ with a calorific value of 16.17 MJ/m^3. This is equivalent to 4527.6 MJ for the whole batch.

While using rice husks the average volume of gas generated was $580m^3$ with a calorific value of 13.18 MJ/m^3. This is equivalent to 7644.4 MJ for the batch

While using maize combs the average volume of gas generated was $420m^3$. The calorific value of this syngas is 12.1 MJ/m^3. This is equivalent to 5082.0 MJ for the batch

Assuming 50% thermal efficiency of the gas driven engine, the output energy of the engine is:

4527.6 MJ x 50% = 2263.8 MJ.

7644.4 x 50% = 3822.2 MJ.

5082.0 x50% = 2541.0 MJ

This is the mechanical input fed to a generator. Assuming the generator and the speed governor operate at 35% efficiency and using the relationship of 1 kWh of electricity output = 3.6 MJ then,

$\frac{2263.8 \times 35\%}{3.6}$ = 220.1 kWh – from saw dust

$\frac{3822.2 \times 35\%}{3.6}$ = 371.6 kWh – from rice husks

$\frac{2541.0 \times 35\%}{3.6}$ = 247.04 KWh – from maize combs

This gas is therefore sufficient to directly drive a 10-kWe AC synchronous generator at a speed of 1,800 rpm producing 220 volt current, which can supply a total of 16 pieces of 50-watt bulbs, for 8 to 10 hours continuous operation. This result shows that if this waste at the dumpsite was gasified it contains a lot of energy potential.

Conclusion

The study found that 25Kg of rice husks fed to the gasifier, produced 580±4.2 m^3 of syngas, with sawdust producing 480±2.8 m^3 and maize combs producing 420±3.1 m^3 for the same weight of feedstock. Syngas from rice husk was found to contain 9.81±0.99% CH_4, 28.55±0.99% CO, 12.59±0.99% CO_2 7.44±0.99% N_2, 8.34±0.99% O_2 and 34.06±1%H_2 while sawdust gave 12.06±1.13% CH_4, 34.34±1.13% CO, 8.24±1.1% CO_2 5.11±1.1% N_2, 5.96±1.13% O_2 and 34.4±1.1% H_2. The calorific value of syngas from sawdust was 16.17 MJ/m^3while rice husks had 13.18 MJ/m^3 with maize combs giving 12.1 MJ/m^3. The higher content of CH_4 and CO in sawdust contributes to its higher calorific value than rice husk.

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