Fabrication, Optimization and Purification of Syngas from Rice Husks; A Value Chain Addition Strategy for Rice Farmers in Mwea, Kenya

Paul Njogu, Robert Kinyua and Yusuyuki Nemoto

Abstract - Thermal gasification of biomass provides a potential renewable energy resource in rural areas in Kenya. Rice husk obtained from Mwea, Kenya was converted into combustible gas (syngas) using a locally assembled modified updraft gasifier. The optimal gas production was achieved at a temperature of 700 °C with injection of limited supply of air, the resultant gas was purified using series of gas cleaning and cooling devices; namely concurrent spray water tower, countercurrent spray water tower, a cyclone separator, a venturi scrubber, a solid adsorbent loaded with fine wood dust and series of coarse and fine fabric filters. The raw and upgraded gases were analyzed for compositional analysis. The upgraded gas was used for direct heating in a modified stove and to run a modified internal combustion engine coupled with an electricity generator for electricity generation. Process water recycled and treated before discharge. Spent rice husks which are fully carbonized were used to make energy briquettes and part of it applied to the rice growing pads to improve soil properties. The technology provides energy solutions to off grid communities and also aids in the abatement of climate change. The project was thus qualified as a value chain addition project for rice growers since extra income can be generated through syngas production and sales. Rice is grown in four areas in Kenya namely; Mwea in Kirinyaga county; Ahero and West Kano in Kisumu county and Bunyala in Busia county [2]. Kenya’s rice production has ranged between 45,000 tons and 50,000 tons per year. This Rice milling generates byproducts such as rice husk and rice straw [1]. Rice husk surrounds the paddy grain. During milling of paddy about 78% of weight is produced as rice, broken rice and bran, the rest 22% of weight of paddy is produced as husk [1,2]. The residues can be utilized as animal feed, soil conditioner and as a renewable energy resource. Rice straw is currently being bailed for sale as animal feed. The use of rice husks however is low due to its low density and poor nutritional value. A small proportion is carbonized in the farms and applied in the rice pads as soil conditioner. The current use of rice husks lag below the current production rates.

I. INTRODUCTION

The demand for energy in Kenya is growing rapidly due to industrial activities which have led to the high increases in prices [1]. The consumption of fossil fuels has gone with a lot of air pollution and the climate change impacts due to increase in the emission of green house gases such as carbon dioxide and other pollutants

Rice is grown in four areas in Kenya namely; Mwea in Kirinyaga county; Ahero and West Kano in Kisumu county and Bunyala in Busia county [2]. Kenya’s rice production has ranged between 45,000 tons and 50,000 tons per year. This Rice milling generates byproducts such as rice husk and rice straw [1]. Rice husk surrounds the paddy grain. During milling of paddy about 78% of weight is produced as rice, broken rice and bran, the rest 22% of weight of paddy is produced as husk [1,2]. The residues can be utilized as animal feed, soil conditioner and as a renewable energy resource. Rice straw is currently being bailed for sale as animal feed. The use of rice husks however is low due to its low density and poor nutritional value. A small proportion is carbonized in the farms and applied in the rice pads as soil conditioner. The current use of rice husks lag below the current production rates.

Direct use of rice husks as an energy source is hampered by low density and low heat value. It is thus imperative to convert it into combustible gas. Rice husks contain 75% organic volatile matter and 25% ash [3]. Rice husks can be converted thermally, biologically or chemically to other usable forms of energy like methane gas, liquid fuels (ethanol and biodiesel) and syngas/process gas. This makes it necessary to come up with innovative ways of sustainable utilization of such wastes. The current practice is open burning which leads to transfer of pollutants from land to the atmosphere.

A. Thermapgasification

Thermal gasification processes provide one of the most promising approaches of waste to energy (WtE) conversion for rice husks [3,4]. Thermal gasification makes use of heat in oxygen deficient environments to transform biomass to combustible gas. The combustible gas can be used to power internal combustion engines coupled with electricity generators for electricity generation which can be used in off grid rural electrification in remote areas especially in areas with huge annual biomass yield.
B. Process Zones In Updraft Gasifier

As the fuel moves down in the gasifier it passes through various reaction zones namely drying, pyrolysis and gasification (Plate 1.0).

C. Drying Zone

Here the biomass gets dried due to heat and moisture present in the fuel converts to steam:

Main Feedstock+Heat → Dry Feedstock+H2O [1]

D. Pyrolysis Zone

Pyrolysis is a thermo chemical decomposition of biomass into a range of useful products, either in the total absence of oxidizing agents or with a limited supply that does not permit gasification to an appreciable extent. It is one of several reaction steps or zones observed in a gasifier. During pyrolysis, large complex hydrocarbon molecules of biomass break down into relatively smaller and simpler molecules of gas, liquid, and char. It takes place at a temperature greater than 250°C [3]:

Main Feedstock + Heat → simple molecules + H2O [2]

E. Oxidation/Combustion Zone

An oxidation or burning zone is formed in the section where air/oxygen is supplied. These combustion reactions are highly exothermic and cause a rapid temperature increase up to 1100-1500°C. The reactions are as follows [3]:

\[ C + O_2 \rightarrow CO_2 + 393 \text{ MJkg mole} \] (3)

\[ 2H_2 + O_2 \rightarrow 2H_2O + 242 \text{ MJkg mole} \] (4)

F. Reaction Zone

This is the main zone of gasifier where we get the product or Syngas. The reactions are as follows:

\[ C + O_2 \rightarrow 2CO -164.9 \text{ MJkg mole} \] (5)
\[ C + H_2O \rightarrow CO + 2H -122.6 \text{ MJkg mole} \] (6)
\[ CO + H_2O \rightarrow CO_2 + H_2 + 42.3 \text{ MJkg mole} \] (7)
\[ C + 2H_2 \rightarrow CH_4 +75 \text{ MJkg mole} \] (8)
\[ CO + 3H_2 \rightarrow CH_4 + H_2O -205.9 \text{ MJkg mole} \] (9)

The mixture of gases produced (eq. 9) in this zone is called Syngas or producer gas.

G. Advantages of Husk Gasification

The conversion of rice husks to syngas provides a value addition strategy to the value chain of rice production. This approach will present new products for sale, soil improvements as well as providing an environmentally sound way of handling agricultural wastes. This technology will help convert the big heaps of rice husks in rice mills and small mills to renewable energy sources. The carbonization of husks also provide a climate mitigation opportunity due to the fact that the carbonized product yields a permanent storage for carbon thus mitigation carbon dioxide emissions [3,4,5].

The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at higher temperatures. Syngas may be burned directly in gas engines, used to produce methanol and hydrogen, or converted using chemical processes into synthetic fuel [3,6]. The high-temperature process refines out corrosive ash elements such as chloride and potassium, allowing clean gas production [7,8,9].

II. MATERIALS AND METHODS

The study was conducted at the Institute of Energy and Environmental Technology, Jomo Kenyatta University of Agriculture and Technology.

A. Gasifier Design and Fabrication

An updraft gasifier was designed and fabricated with cleaning accessories and air injection systems. The gasifier was made using stainless steel sheet and mild steel for outside cover. The gasifier was fitted with temperature probes and pressure gauges to monitor operation parameters. The plant was run using rice husks; saw dust. The plant was operated in both batch and continuous modes. The schematic is indicated in Fig. 1.0 and Plate 1.0. The updraft gasifier is a medium size unit with 400 mm internal diameter reactor with 75 mm gas outlet, 220 volt electric blower for air injection in gasifying rice husks to produce carbon monoxide (CO), methane (CH4) and hydrogen (H2) carbon dioxide (CO2), nitrogen (N2) and traces substances. The reactor has a 150 mm lagging to prevent heat losses and an internal perforated 3 inches pipe for gas delivery. Rice husk is fed at the top end of the reactor
manually. Char is removed from bottom using a screw conveyor.

B. Feedstock Analysis
Rice husks were analyzed to ensure it met the desired quality for use in the gasifier furnace without problems. Proximate analyses were performed to determine the ash content, moisture content and volatile organic compounds. Ultimate analyses were also conducted to determine carbon, oxygen, nitrogen and sulphur contents. Standard methods of analysis were used in all cases [10].

C. Syngas Production and Upgrading
The rice husks were dried in the open to achieve moisture contents of <14%. The feed stocks were loaded into the reactor manually. The gas production commenced after ten minutes after ignition of biomass, the raw gas was passed through a series of cleaning and cooling devices as indicated in Fig. I. The raw gas was upgraded by passing through the gas – cleaning and cooling devices which consisted of; wet scrubbers (concurrent and countercurrent spray water towers), a cyclone separator, a venturi separator, a saw dust adsorbent and a coarse and fine fabric filter (Fig. I).

D. Syngas Analysis
The resultant gas was analyzed using gas chromatographic analyzer with a thermal conductivity detector (GC-TCD). The gas was sampled using gas sampling balloons and injected into the detector without any pretreatment. Samples were run in triplicates. The peak areas were determined and the gas composition derived in percentages.

E. Process Optimization
The gas production was related to the gasification temperatures and air injection rate. The pressure of the system was also monitored in order to come up with the optimal operating conditions. The moisture content was also monitored and related to syngas yields.

F. Combustion Emission Analysis
The emissions were analyzed for oxides of nitrogen oxides (NOx), carbon monoxide and carbon dioxide concentration. To ensure the safety of the plant the workers were provided with personal protective equipments such as dust coats, dust masks and eye protection devices. The plant was also designed to allow maximum air flow to and from outdoor environment. A carbon monoxide detector meter was fitted two meters above ground, the meter is an automatic device with an alarm that turns on once the concentration reach 10 ppm.

III. RESULTS AND DISCUSSIONS
A. Rice Husk Gasifier
The plant layout is illustrated in Figure 1.0. The gasification system includes: Feeder, A fluidized bed updraft gasifier, Cyclone separator, Air Injection port, Blower, Ash collection device, two water spray towers, A venturi scrubber, process water recirculation unit, A solid adsorbent bed, A fabric Filter, A smoke Vent, Gas transport pipes and control valves and an automatic controlling device and a modified 5KW Genset.

![Figure I. A Schematic for the Gasification Plant at JKUAT, Kenya](image)

<table>
<thead>
<tr>
<th>Compos...</th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>O</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>30-40.5</td>
<td>4.1-4.7</td>
<td>0.4-0.7</td>
<td>0.5-0.8</td>
<td>0.09-0.15</td>
</tr>
<tr>
<td>Mean ± std dev</td>
<td>38.3 ± 3.2</td>
<td>4.2 ± 0.6</td>
<td>0.5 ± 0.2</td>
<td>0.6 ± 0.1</td>
<td>0.11 ± 0.01</td>
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</table>

<table>
<thead>
<tr>
<th>Table II</th>
<th>Ultimate Analysis Data for Rice Husks (% Dry WT)</th>
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<tr>
<td>Compos...</td>
<td>C</td>
</tr>
<tr>
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</tr>
<tr>
<td>Mean ± std dev</td>
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</table>

Plate 2.0 Gasifier in the Shed
PROXIMATE ANALYSIS DATA FOR RICE HUSKS (% dry wt.)

<table>
<thead>
<tr>
<th>Component</th>
<th>Ash</th>
<th>Moisture</th>
<th>Volatiles</th>
<th>Fixed carbon</th>
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<tbody>
<tr>
<td>Percentage</td>
<td>10-12.3</td>
<td>8-18.8</td>
<td>68-75.3</td>
<td>14-15.7</td>
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<tr>
<td>Mean ± std. dev</td>
<td>11.5 ± 1.3</td>
<td>12.2 ± 2.2</td>
<td>69.3 ± 5.4</td>
<td>14.3 ± 1.3</td>
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</table>

TABLE III
SYNGAS COMPOSITIONAL DATA

<table>
<thead>
<tr>
<th>Component</th>
<th>CO</th>
<th>H₂</th>
<th>CH₄</th>
<th>CO₂</th>
<th>N₂</th>
<th>Others</th>
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</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>16.5-17.5</td>
<td>4.1-4.5</td>
<td>6.8-7.2</td>
<td>14.5-16.1</td>
<td>16.9-45.7</td>
<td>-1.24-1.4</td>
</tr>
<tr>
<td>Mean ± std. dev</td>
<td>16.9 ± 1.1</td>
<td>4.2 ± 0.5</td>
<td>7 ± 0.5</td>
<td>15.1 ± 0.5</td>
<td>25.2 ± 5</td>
<td>1.4 ± 0.3</td>
</tr>
</tbody>
</table>

TABLE IV
PERFORMANCE PARAMETERS OF GASIFICATION FURNACE AND COOLING AND CLEANING SYSTEM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Updraft gasification plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator rated output power (KW)</td>
<td>5</td>
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<tr>
<td>Volume gas produced (Nm³/hr)</td>
<td>17</td>
</tr>
<tr>
<td>Gas temperature of gasification furnace outlet (°C)</td>
<td>350 - 490</td>
</tr>
<tr>
<td>Gas temperature of outlet after cleaning and cooling (°C)</td>
<td>55</td>
</tr>
<tr>
<td>Consumption of biomass (ton/hr)</td>
<td>14</td>
</tr>
<tr>
<td>Volume of circulating water (m³/hr)</td>
<td>0.1</td>
</tr>
<tr>
<td>Ash removing manner</td>
<td>Scooping</td>
</tr>
<tr>
<td>Device of gas cleaning and cooling system</td>
<td>Cyclone separator, 2 spray scrubbers, 1 venturi scrubber, filter (removing dust, tar and cooling), roots blower</td>
</tr>
</tbody>
</table>

IV. CONCLUSION AND RECOMMENDATIONS

The present study show great potential for conversion of rice husks into clean gas fuels for electricity generation. The plant was found to work optimal at a moisture content <15%, 700 °C. Though some power supply is required during start up the electricity produced can sustain the plant with an 85% surplus that can be used for rural electrification. The plant if upscale can provide cheap and clean energy to rural communities off power transmission grids.

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REFERENCES