ANALYTICAL METHOD TO DETERMINE THE POTENTIAL OF USING RICE HUSK FOR OFF GRID ELECTRICITY AND HEAT GENERATION

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ABSTRACT
This work develops an analytical method of determining the captive Combined Heat and Power (CHP) potential of the rice husk produced at the rice mills. Technologies whose commercial efficacy has been established for generating electricity and heat from rice husk were analysed using sets of thermo-chemical and thermodynamics equations to determine their CHP potential for the same amount of input rice husk. Four power plants were considered: boiler-steam turbine combination labelled Plant A, gasifier-boiler-steam turbine combination labelled Plant B, gasifier-gas turbine combination labelled Plant C and gasifier-Internal Combustion engine combination labelled Plant D. Results from the analysis shows that 4.85 kg, 6.82 kg, 0.87 kg, and 0.97 kg are required to produce a kilowatt-hour of electricity by plants A, B, C and D respectively; while the heat co-generation potential of the plants A, B, C and D obtained are 10,051.09 MJ/hr, 7,136.24 MJ/hr, 4,182.95 MJ/hr and 6,604.67 MJ/hr respectively. Hence, a gasifier-gas turbine CHP plant is the most viable means of utilizing rice husk for off grid CHP generation while a gasifier-boiler-steam turbine CHP plant is the least viable.

Keywords: rice husk ash, renewable energy, heat generation, CHP, gasifier-gas turbine CHP

1. INTRODUCTION
The quantity of rice husk waste produced at rice mills is substantial, 20 % by weight of milled paddy [1]. It is therefore a common sight to see huge heaps of rice husk dumps around the vicinity of rice mills in areas where the husk is not used by activities such as land filling, animal bedding, fertilizer, as well as domestic heating and cooking fuel [2, 9]. These rice husk dumps poses environmental concerns such as pollution of the atmosphere when in a bid to dispose of the waste, mill operators burn the heaps. A large and valuable expanse of land is also taken up by these rice husk dumps. To ameliorate the problems posed by these rice husk dumps, an effective means of disposal or usage of the husk ought to be adopted, hence this analysis of determining the CHP potential of rice husk.

One research puts the energy content of rice husk at 13.643 MJ/kg [8], but the average energy content of rice husk is 15.84 MJ/kg [3]. This energy can serve as input fuel in a chain of processes for the co-generation of electricity and heat. The research analyzes the electricity and heat generation potential of rice husk via technologies whose commercial status has been established.

2. METHODOLOGY
Sets of thermo-chemical and thermo-dynamics equations were used to analyze the feasibility of electricity and heat generation by the alternative technologies utilizing rice husk as fuel. Only technologies that have been proven commercially for electricity and heat generation utilizing rice husk were considered in this study, hence thermo-chemical processes of gasification and combustion were considered. Pyrolysis is still undergoing development for commercial electricity production [4]. Bio-chemical processes for commercial electricity generation are still undergoing development [3]. The possible technology combinations to achieve a husk to electricity/heat energy conversion are summarized in Figure 1.

Figure 1 shows the four possible plant technology combinations, namely:

i. Plant A: steam turbine plant via heat from husk combustion
A. Ame-Oko, et al.  

**ANALYTICAL METHOD TO DETERMINE THE POTENTIAL OF USING RICE HUSK FOR OFF GRID ELECTRICITY AND..., A. Ame-Oko, et al.**

ii. Plant B: steam turbine plant via heat from syngas combustion  
iii. Plant C: gas turbine plant via syngas from gasification  

![Figure 1: Husk to electricity/heat technology combinations](image)

Figure 1 shows that, there are two major processes of converting biomass into energy that will in turn be used to generate electricity and heat. These are combustion and gasification. The direct combustion of rice husk biomass produces heat energy as its output which can be used to produce steam in boilers for the generation of heat and electricity when coupled to a steam turbine generator (Plant A). The gasification process on the other hand produces syngas as its output. The syngas can be burnt in a boiler to produce steam for a steam turbine generator. Plant B, therefore, is made up of three distinct modules - gasifier module, boiler module and turbine generator module. Plant B operates just like plant A with the difference being the fuel being burnt in the boiler. The set of equations used to determine the electric power output and the thermal output of Plant A also served for Plant B except for Equation (2) which was replaced by Equation (6). The total input energy to Plant B is given by:

\[
E_i = H_r \times \xi_{c} \times v
\]

Where: \(\xi_{c}\) is the efficiency of the gasifier in percentage (%)

3.2 Plant B  
Plant B requires that the rice husk is first converted to syngas via gasification. The syngas now serves as the fuel burnt in the boiler to produce steam for a steam turbine generator. Plant B, therefore, is made up of three distinct modules – gasifier module, boiler module and turbine generator module. Plant B operates just like plant A with the difference being the fuel being burnt in the boiler. The set of equations used to determine the electric power output and the thermal output of Plant A also served for Plant B except for Equation (2) which was replaced by Equation (6). The total input energy to Plant B is given by:

\[
E_i = H_r \times \xi_{c} \times v
\]

Where: \(\xi_{c}\) is the efficiency of the gasifier in percentage (%)

3.3 Plant C  
Plant C is a combination of a gas turbine generator module and a gasifier module. The rice husk is gasified in the gasifier module to produce syngas which serves as fuel for the gas turbine module for electricity production. Equations (1), (6), (7) and (8) were used to determine the electric power output and the thermal output of Plant C. The electric power output and heat output of Plant C are given by,

\[
P_e = \xi_{GTe} \times E_i \times c_f
\]

\[
P_t = \xi_{GTh} \times E_i
\]

Where: \(\xi_{GTe}\) is the electrical efficiency of the gas turbine generator in percentage (%); \(\xi_{GTh}\) is the thermal
efficiency of the gas turbine generator in percentage (%)

3.4 Plant D

Plant D comprises of a gasification module coupled to an IC engine. The rice husk undergoes gasification in the gasification module to produce syngas which in turn serves as input fuel for the IC engine. Equations (1), (6), (9) and (10) were used to determine the electric power output and the thermal output of Plant D. The electric power output and heat output of Plant D are given by,

\[
P_e = \xi_{ICE} \times E_i \times c_f \tag{9}
\]

\[
P_t = \xi_{ICT} \times E_i \tag{10}
\]

Where: \(\xi_{ICE}\) is the electrical efficiency of the IC engine in percentage (%) and \(\xi_{ICT}\) is the thermal efficiency of the IC engine in percentage (%).

4. DATA COLLECTION

Relevant data was collected from a field study of an existing rice mill as well as scholarly literature which were used to evaluate the CHP potential of the four plants. The data collected and their sources are summarized in Table 1.

Table 1: Data collected and sources

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHV of rice husk</td>
<td>15.84 MJ/kg</td>
<td>[3]</td>
</tr>
<tr>
<td>Electrical efficiency IC Engine</td>
<td>33 %</td>
<td>[7]</td>
</tr>
<tr>
<td>CHP efficiency IC Engine</td>
<td>78 %</td>
<td>[7]</td>
</tr>
<tr>
<td>Electrical efficiency, gas turbine generator</td>
<td>36.5 %</td>
<td>[7]</td>
</tr>
<tr>
<td>CHP efficiency, gas turbine generator</td>
<td>65 %</td>
<td>[7]</td>
</tr>
<tr>
<td>Electrical Efficiency, steam turbine generator</td>
<td>7 %</td>
<td>[7]</td>
</tr>
<tr>
<td>CHP efficiency, steam turbine generator</td>
<td>79.57 %</td>
<td>[7]</td>
</tr>
<tr>
<td>Efficiency of fluidised boiler (HHV)</td>
<td>67 %</td>
<td>[7]</td>
</tr>
<tr>
<td>Efficiency of gasifier (HHV)</td>
<td>71 %</td>
<td>[7]</td>
</tr>
<tr>
<td>Rice husk available for CHP generation per year</td>
<td>3507678 kg</td>
<td>Field study</td>
</tr>
<tr>
<td>Hours of Rice Mill operation per year</td>
<td>2688 hrs</td>
<td>Field study</td>
</tr>
</tbody>
</table>

5. RESULTS AND DISCUSSION

The results from the evaluation of the energy output of plants A, B, C and D are presented. This comprises the electric power output and the corresponding cogenerated heat output of the Plants for the same quantity of input husk. Figure 2 shows the total electric power output possible for each plant based on the quantity of husk available for electricity and heat generation at the mill, while Figure 3 shows the corresponding cogenerated heat output for the plants. Table 2 shows the annual electricity potential of the four plants and their corresponding quantity of husk required to produce 1 kWh of electricity by the plants.

Table 2: Husk consumption rate and annual electrical energy production

<table>
<thead>
<tr>
<th>PLANT</th>
<th>kWh</th>
<th>kg/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>723,905.28</td>
<td>4.85</td>
</tr>
<tr>
<td>B</td>
<td>513,972.48</td>
<td>6.82</td>
</tr>
<tr>
<td>C</td>
<td>3,999,985.92</td>
<td>0.87</td>
</tr>
<tr>
<td>D</td>
<td>3,616,435.2</td>
<td>0.97</td>
</tr>
</tbody>
</table>

The power output of the plants A, B, C and D is presented in Figure 2. The graph shows that for the same quantity of input husk (3,507,678 kg), Plants A, B, C and D can generate 269.31 kW, 191.21 kW, 1,488.09 kW and 1,345.40 kW of electric power respectively. This translates to an annual electricity generation potential of 723,905.28 kWh, 513,972.48 kWh, 3,999,985.92 kWh and 3,616,435.2 kWh for Plant A, Plant B, Plant C and Plant D respectively. Plant C is the most efficient of the four plants requiring 0.87 kg of husk per kWh of electricity generation. Plant B is the
6. CONCLUSION

Through a simple analytical model, a method of determining the CHP potential of rice husk for off grid electricity and heat supply was developed. The results obtained provide a relationship between the quantity of husk required to produce a unit of electricity and heat for the various conversion technologies considered.

The results shows that a gasifier-gas turbine CHP plant is the most efficient means of utilizing rice husk for CHP applications while a gasifier-boiler-steam turbine CHP plant is the least efficient.

7. REFERENCES


