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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

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

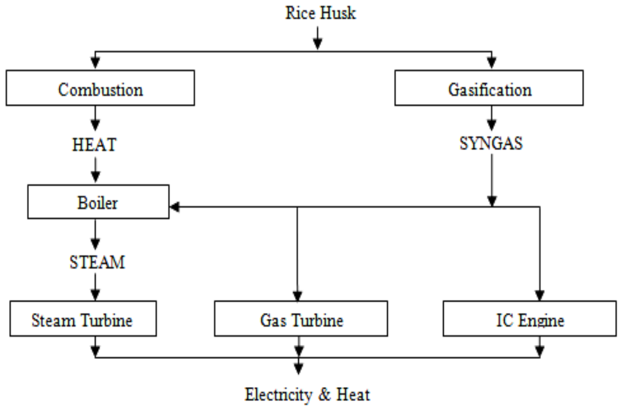

Figure 1: Husk to electricity/heat technology combinations

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 heat and electricity generation via steam turbine generator (Plant B) or the syngas is used as fuel to produce electricity and heat via a gas turbine generator (Plant C), or the syngas is used as fuel in an IC engine to generate electricity and heat (Plant D). The analysis of the electricity and heat generation potential for the four plants is presented in the following subsections.

3. THE POTENTIAL ANALYSIS OF THE ELECTRICITY AND HEAT GENERATION OF THE PLANT

3.1. Plant A

Plant A is made up of two distinct major modules: the boiler module and the steam turbine generator module. The rice husk is burnt in the boiler to produce heat which increases the temperature of water to produce super heated steam at high pressure. The steam at the designed temperature, pressure and flow rate is let into the turbine chamber where it expands and does work by rotating the turbine which is coupled to a generator shaft for electricity production. The discharged steam from the turbine is condensed and pumped back to the boiler to complete the Rankine cycle on which the steam turbine generator operates [5]. The set of equations used to determine the electric power output and the thermal output of the plant is given by [5] as:

$$H_r = Q \div h \quad (1)$$

$$E_i = H_r \times \upsilon \quad (2)$$

$$\dot{H} = E_i \times \xi_B \quad (3)$$

$$P_e = \xi_{STe} \times \dot{H} \times c_f \quad (4)$$

$$P_t = \xi_{STt} \times \dot{H} \quad (5)$$

Where: H_r is the input husk rate to the system in kg/hrm, Q is the rice husk quantity in kg, h is the number of hours of operation of the plant per year, E_i is the total input energy to the system in MJ/hr, υ is the HHV of the rice husk fuel in MJ/kg, $\dot{H}$ is the input heat to steam turbine generator in MJ/hr, ξ_B is the efficiency of boiler, ξ_{STe} is the electric efficiency of the steam turbine in percentage (%), ξ_{STt} is the thermal efficiency of the steam turbine in percentage (%), c_f is a conversion factor of 0.27777778 [6], P_e is the electrical power output in kW and P_t is the heat output in MJ/hr

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:

$$E_i = H_r \times \xi_G \times \upsilon \quad (6)$$

Where: $\xi_G$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,

$$P_e = \xi_{GTe} \times E_i \times c_f \quad (7)$$

$$P_t = \xi_{GTt} \times E_i \quad (8)$$

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

$$P_e = \xi_{ICe} \times E_i \times c_f \quad (9)$$

$$P_t = \xi_{ICt} \times E_i \quad (10)$$

Where: ξ_{ICe} is the electrical efficiency of the IC engine in percentage (%) and ξ_{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

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

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.

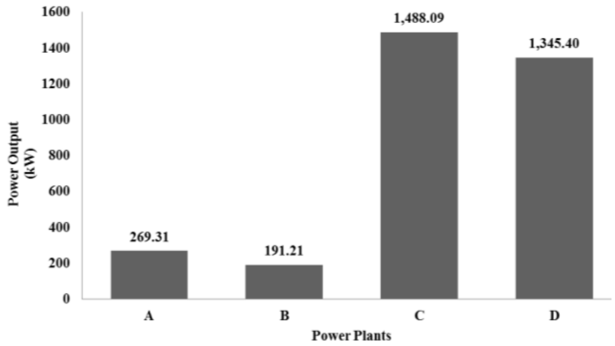

Figure 2: Power generation of the Plants based on husk availability

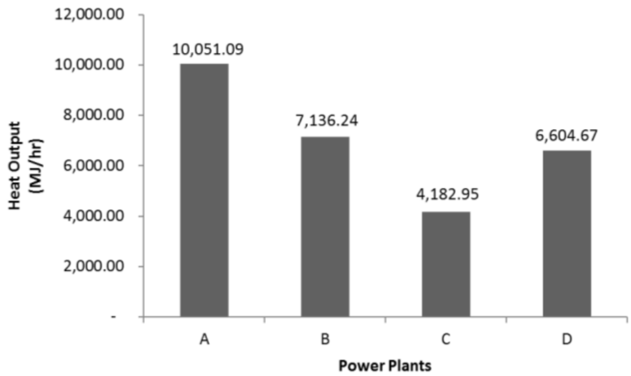

Figure 3: Heat output of the Plants based on husk availability

Table 2: Husk consumption rate and annual electrical energy production

	kWh	kg/kWh
PLANT A	723,905.28	4.85
PLANT B	513,972.48	6.82
PLANT C	3,999,985.92	0.87
PLANT D	3,616,435.2	0.97

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 least efficient plant requiring 6.82 kg/kWh. Plants A and D requires 4.85 kg/kWh and 0.97 kg/kWh respectively.

The potential for heat co-generation for the plants is shown in Figure 3. Plant A can generate 10,051.09 MJ/hr of heat. Plants B, C and D Can generate 7,136.24 MJ/hr, 4,182.95 MJ/hr and 6,604.67 MJ/hr of heat respectively.

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.

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