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The Effect of Using Biomass Gasification as Source of Energy to Small Scale Bio-ethanol Production

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Abstract: **The process heat integration with other energy sources has been considered as an alternative to minimize the energy cost incurred by small-scale bio-ethanol plants. In this paper the result of a study conducted to evaluate the effect of utilizing biomass gasification as source of energy in bio-ethanol production is presented. The study assessed the effect in bio-ethanol production cost when conventional energy sources are replaced with biomass gasification. Material characterization was done, followed by fabrication and testing of a 100 kW updraft gasifier prototype. The developed 100 kW gasifier was tested using rice husk which are readily available. The properties of rice husk were analyzed through proximate analysis. These properties were used in preparing the mathematical model for mass and energy balance. The developed gasifier was found to operate at an efficiency of 51% and produces syngas with calorific value estimated to be 2.02 MJ/kg. Utilizing rice husk gasification can replace the conventional energy sources with estimated 17.6% energy cost saving to bio-ethanol plants. These results show the potential of using biomass gasification as sources of energy to small scale bio-ethanol production plants.**

Keywords: **Biomass, gasification, Bio-ethanol, economics.**

1. INTRODUCTION

1.1 Background:

Bioethanol is produced through sugar fermentation of sugarcane juice, molasses, corn, cassava, and other starch related materials via distillation process. The major challenge with bio-ethanol production is its economic competitiveness against fossil fuel due to its high production cost caused by high energy cost incurred by the process. This process is energy intensive which requires 9.74 to 13.84 MJ to produce one litre of ethanol (Hohmann and Rendleman, 1993); (Shapouri et al., 2002). The objective of this study was to develop a process heat integration model for small scale bio-ethanol plant through mass and energy balance. Among of the specific objectives of this study was to develop a mass and energy balance for process heat integration, determining rice husk properties, fabricate an updraft gasifier prototype and determine its performance characteristics, establish financial costs of using producer gas as source of energy in small scale bio-ethanol plants.

2. METHODS

To achieve the objective of this study, the following methods were adopted;

2.1 Developing the Process Flow Diagram (PFD):

The PFD for bio-ethanol production was developed and considered to be the guideline in making the mass and energy balance in the model (refer Fig. 1).

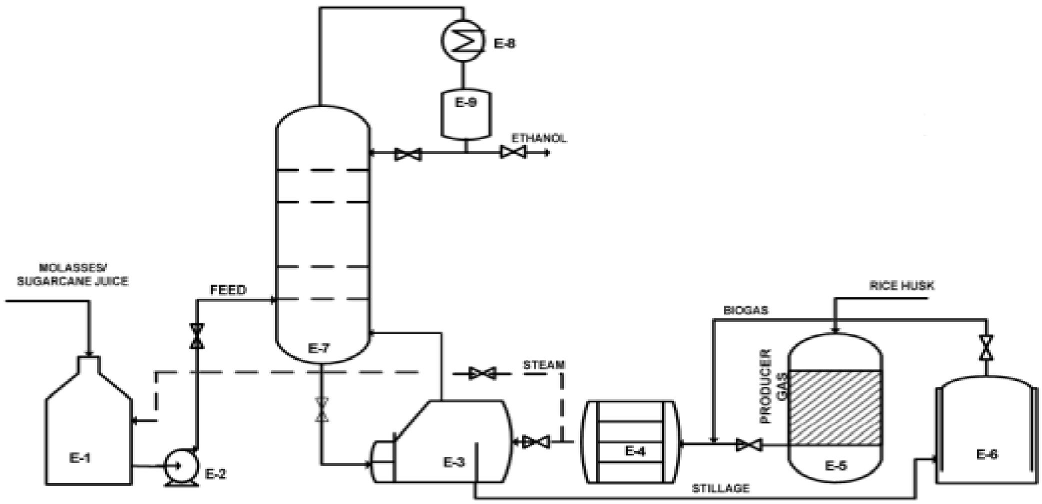

Fig.1: PFD for Small Scale Bio-Ethanol Production

Legend:

E-1 Fermenter; E-2 Pump; E-3 Reboiler; E-4 Boiler; E-5 Gasifier; E-6 Biodigester; E-7 Distillation column; E-8 Condenser; E-9 Reflux tank

2.2 Developing of Model Equations:

This approach involved derivation of equations and calculation of mass and energy balance for each unit operation making the entire process. This was done based on the laws of conservation of mass and energy, and application of some thermodynamics principles. The formulated equations were solved to obtain the concentration of species involved during gasification.

2.3 Determination of Proximity Analysis:

The proximate analysis to evaluate the characteristics of gasifier feedstock (rice husks) was done using an oven, muffle furnace and weighing balance. This analysis was done based on wet and dry basis. Wet basis analysis is an analysis done without removing water into the material tested, while the dry basis test is done after water is been removed. Table 1 presents the formula used in this analysis.

TABLE 1: FORMULAE USED IN PROXIMATE ANALYSIS

Parameter on Test	Formulae (On Wet Basis)	Formulae (On Dry Basis)
Moisture Content	$\frac{(Initial\ Mass - Dry\ Mass) * 100}{Initial\ Mass}$	$\frac{(Initial\ Mass - Dry\ Mass) * 100}{Dry\ Mass}$
Volatile Matter	$\frac{(Dry\ Weight - Weight\ of\ Char) * 100}{Initial\ Weight}$	$\frac{(Dry\ Weight - Weight\ of\ Char) * 100}{Dry\ Weight}$
Ash Content	$\frac{Weight\ of\ Ash * 100}{Initial\ Weight}$	$\frac{Weight\ of\ Ash * 100}{Dry\ Weight}$
Fixed Carbon	Fixed Carbon = 100% - [%Moisture - %Volatile +%Ash]	Fixed Carbon = 100% - [%Volatile + %Ash]

2.4 Fabrication and Testing an Updraft Gasifier:

A 100 kW small-scale updraft gasifier prototype was constructed, operated and tested using rice husk as feestock.

2.5 Water boiling test:

The heat energy absorbed by water in a water boiling test and heat loss by flue gases was used to estimate energy value for the syngas produced. The total amount of heat (absorbed by water and lost by flue gases) was estimated by using a formula;

$q_w = [m_w * Cp_w * (Tb – Ti) + m_wL]/dt$

Where;

mw = mass of water, Cpw = specific heat capacity of water, Ti, and Tb = initial and boiling temperature respectively of water, L = latent heat of vaporization of water, dt = rate of change of time.

2.6 Energy Cost Analysis:

The impact on process energy cost was evaluated in an Excel sheet, whereby the price of raw material, calorific value of the material, and conversion efficiency were considered in the analysis (Table 3).

3. RESULTS

3.1 Meeting the Process Energy Demand through Gasification:

The mathematical model analysis results for mass and energy balance (See Fig. 2), shows the gasifier was operating at fuel consumption rate (FCR) of 46 kg/hr, ratio of syngas production/ FCR of 2.33, and LHV of syngas being assumed to be 4.54 MJ/m^3.

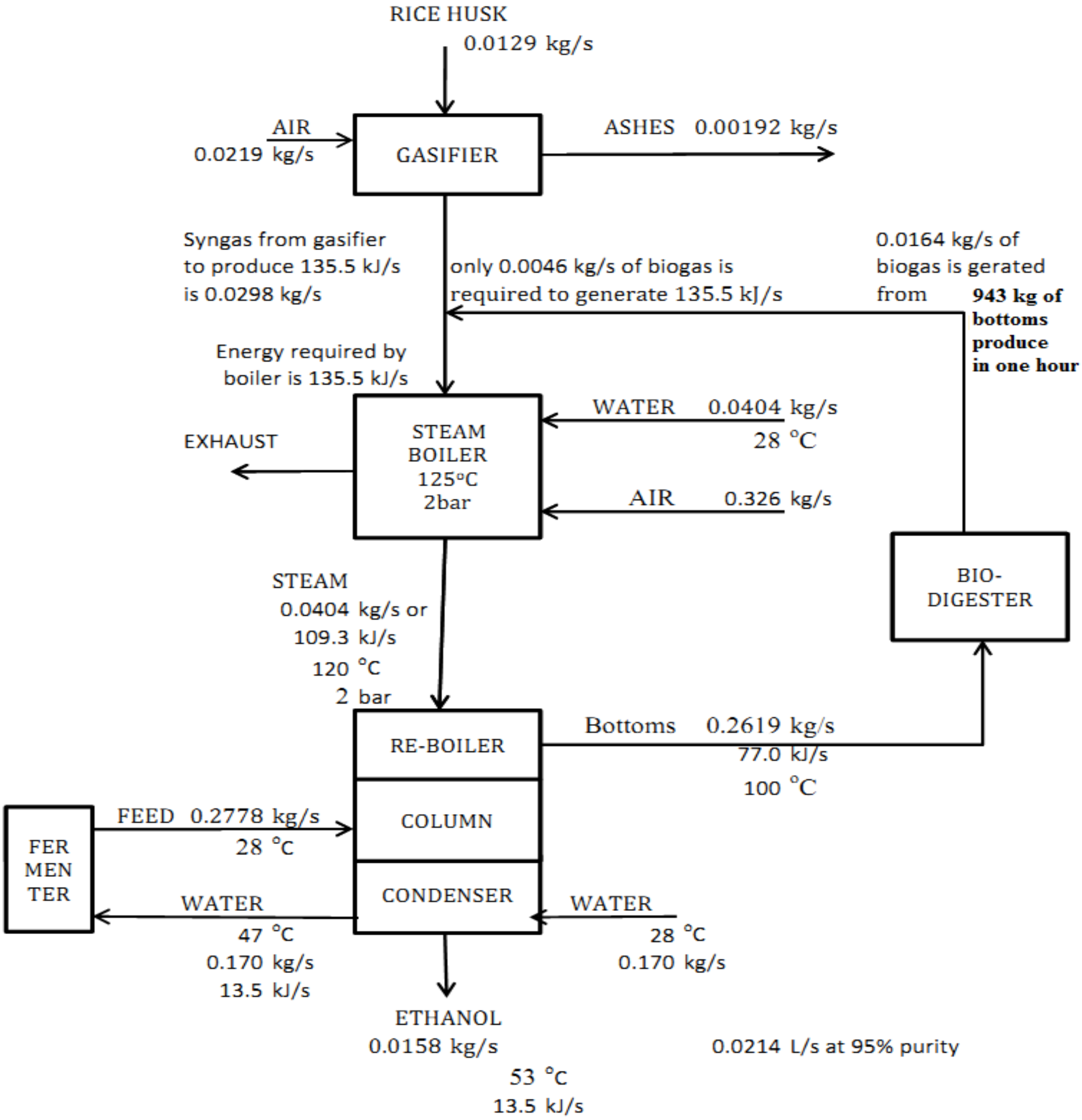

Fig.2: Mathematical Model for Material and Energy Balance

The actual results from the gasifier prototype are presented in Table 1. These results show that the developed gasifier was operating near to its optimal operating parameters.

TABLE 1: RESULTS FROM THE GASIFIER

Parameter	Unit	Value
Air intake flow rate	Kg/s	0.05-0.07
Gas outlet flow rate	m3/h	26.87
Equivalence Ratio	Φ	0.3-0.4
Specific gasification rate	kgh-1m-2	79.92
Gasifier Efficiency	η	51
LHV of producer gas	MJ/kg	2.02
Heat loss by gasifier	%	6.14

Proximate analysis for rice husk was carried out to quantify moisture content, volatile matter, fixed carbon, ash content, and its energy value. Table 2 shows a comparison of proximate analysis results between the tested samples for rice husk and results obtained from literature (Mohamad et al., 2008); (Lee Ven Han, 2004); (Rozainee et al., 2010); (Thipwimom et al., 2004).

TABLE 2: PROXIMATE ANALYSIS RESULTS

Parameter	Laboratory results (dry basis)	Literature data (dry basis)	% difference (dry basis)
Moisture (%)	10.88	8.45	22.3%
Volatile (%)	65	65.08	0.1%
FC (%)	20.19	14.87	26.3%
Ash (%)	14.91	17.61	25.7%
Bulk density (kg/m3)	128	115.73	9.6%
HHV (MJ/kg)	15.348	15.2	0.9%
LHV (MJ/kg)	14.105	14.22	0.8%

3.2 The Equivalence Ratio for Gasification:

It is a ratio of stoichiometric air fuel ratio to actual air fuel ratio that determines syngas production by the gasifier. In the experiments, syngas was produced at the equivalence ratio ranging from 0.3 to 0.4, and the respective velocity of air flow into the gasifier was 6.5 m/s and 4.3 m/s.

3.3 Temperature Profile in the Gasifier:

Fig.3 shows temperature variation within the gasifier zones (combustion, gasification, pyrolysis, and drying). The maximum temperatures recorded were lower than the recommended values in respective zones.

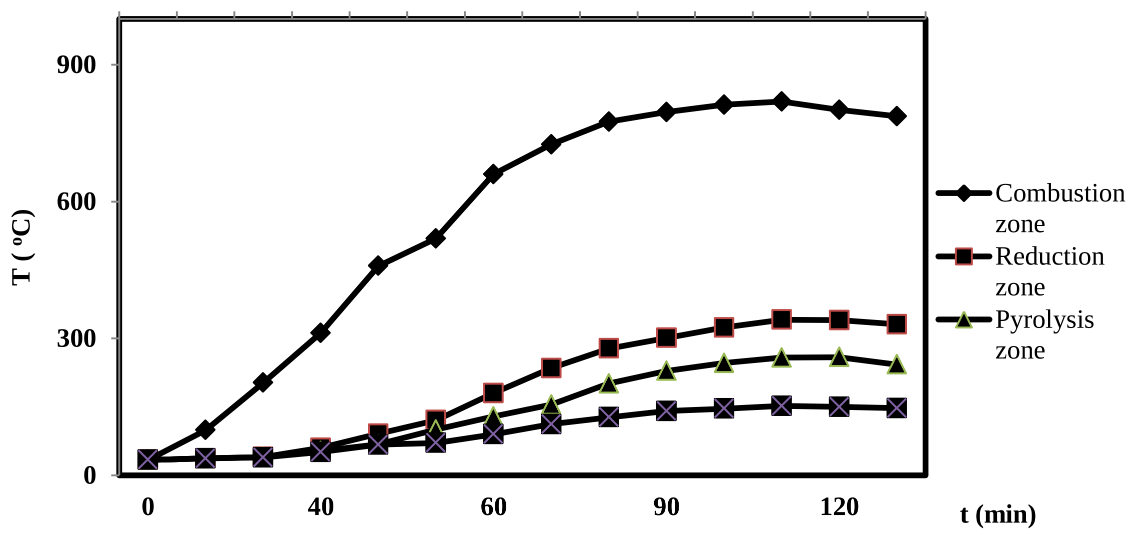

Fig. 3: Temperature Variation within Gasifier Zones

From the graphs, temperatures increased exponentially until the steady state temperatures were reached. The steady state temperatures decreased when fuel within the gasifier was being consumed to the minimum amount.

3.4 Energy Value of Syngas and Gasifier Efficiency:

Due to the absence of gas chromatograph, the energy value of syngas was estimated to be 2.02 MJ/kg through a water boiling test. Additional to this, a bluish clear flame observed indicated presence of large quantities of CO. Based on these results; the gasifier efficiency was analyzed to be 51%.

3.5 Impact on Bio-ethanol Energy Production Cost:

Table 3 compares different type of fuels which have a potential of being used as energy sources to small scale bio-ethanol production plants. The cost of using electricity energy was considered as a reference conventional energy source. The negative sign in the last column of Table 3 indicates an increase in energy cost, while positive sign indicates a reduction in energy cost when electricity is substituted with other type of fuels. The fuels costs were derived based on the prices found in the energy market in Tanzania, and the percentage of cost saved upon substituting the conventional energy sources with syngas based on the formula below;

$$\text{Percentage of energy cost saved} = \frac{A - B}{A} \times 100$$

Where;

A = Total energy cost required to produce one litre of bioethanol by using electricity energy.

B = Total energy cost required to produce one litre of bioethanol by using other sources of energy such LPG, natural gas, coal, charcoal, IDO, syngas, and electricity itself.

On the other hand, the price of syngas was derived based on the formula below;

$$= \frac{\text{Total operating \& material cost}}{\text{Total syngas energy produced per year}}$$

From this analysis, the cost of syngas was obtained to be 35 Tsh/MJ, and this cost became the base to decide the price of sygas which is 65 Tsh/MJ.

TABLE 3: COST COMPARISON FOR THE POTENTIA ENERGY SOURCES IN BIO ETHANOL PRODUCTION

Energy to produce	Type of fuel	Calorific value of fuel (LHV)		Conversion	Fuel required to produce 1Lt EtOH		Average unit price		Total cost	% of Cost saved
one Lt of ethanol		Quantity	Unit	Efficiency (%)	Quantity	Unit	Amount	Unit	Tsh.	
	LPG	49.4	MJ/kg	70	0.34	kg	2,266	Tsh/kg	772	-145.0
11.786 MJ	Natural gas	38.1	MJ/kg	70	0.44	kg	1,133	Tsh/kg	500	-58.8
	Coal	33.8	MJ/kg	70	0.50	kg	600	Tsh/kg	298	5.2
	Charcoal	20	MJ/kg	70	0.84	kg	625	Tsh/kg	526	-66.8
	Electricity	3.53	MJ/kWh	90	3.71	kWh	85	Tsh/kWh	315	0.0
	IDO (Lt)	41.4	MJ/kg	85	0.33	Lt	800	Tsh/Lt	267	15.0
	Syngas	4.54	MJ/kg	65	3.99	kg	65	Tsh/kg	259	17.6

4. DISCUSSION AND CONCLUSION

The developed mathematical model analysis of mass and energy balance results (Fig.2), shows the possibility of generating syngas from rice husks. To validate this model a 100 kW rice husk updraft gasifier prototype was developed and tested. The test results of the gasifier (Table 1) were compared with the results of the mathematical model, and showed no significant differences. The gasifier experimental results were promising and prompt the adoption of biomass gasification as source of energy to small scale bio-ethanol plants. Prior to gasification experiments, material characterization for the feedstock to be used (rice husk) was carried out. The test results were compared to the results from literature (Table 2), and showed significant differences in moisture, fixed Carbon, and ash contents, however there were no significant differences in volatile matter and material energy value. These characteristics showed a good potential for the material to be used as feedstock for gasification process.

The recorded temperatures in the gasifier zones were lower than the recommended values for syngas to be produced (Fig.2) which was drawn based on rice husk gasification. The reasons suspected to associate with the observed problem were temperature sensors not located exactly on the gasifier zones, lack of good insulation to reduction, pyrolysis, and drying zones which leads to loss of temperature. Normally syngas is produced from a reduction temperature of 700^{o}C to 950^{o}C, and since syngas was produced, it is a proof that temperature within the gasifier reached the gasification/reduction, pyrolysis, and drying temperatures. Comparing the calorific value of syngas produced with syngas in literature data which is from 2.5-5.0 MJ/m3, proves a good performance of the developed updraft gasifier.

Table 3 contains comparisons of various potential energy sources that can be used in small scale bio ethanol production plants. In this table, the direct burning of coal and IDO have positive impact on the energy cost in bio-ethanol production, however direct burning of these fuels have negative side effect on environment as well as on the boiler. This makes syngas from rice husk to be the favorable choice, because it burns cleaner with less environmental impact, and it reduces the energy cost by about 17.67%.

With the energy cost saving of about 17.67% upon substituting the conventional energy sources with syngas from rice husk to small scale bio-ethanol, proves the great potential of gasification technology to meet the energy demand in small scale bio-ethanol production.

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