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Testing and Evaluation of an Updraft Gasifier Using Saba Banana Peel as Feedstock

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ABSTRACT

Saba bananas are widely produced in the Philippines, mainly for food production. The peel of saba was characterized, and some physical properties of it were measured. The heating value, fixed carbon, volatile matter, ash, and moisture content of the peel were also determined. In predicting the elemental composition, the equation of Parikh et al. (2007) was used, yielding an air-to-fuel ratio of 6.92 $kg_{air}/kg_{biomass}$ for combustion. A laboratory-scale prototype updraft gasifier was fabricated and tested for efficiency by boiling water on it. The size of the peel affects the ignition time of the syngas and the burning rate of the biomass. Flow rate affects the amount of heat produced and the equivalence ratio during gasification. Thermal efficiencies in different settings are less than 20% due to system heat loss. The highest efficiency was obtained with a low airflow setting, while the lowest efficiency was yielded at a high airflow setting. At an equivalence ratio of 0.208, about 500g of saba peel produced around 1562.63 kJ of heat with a thermal efficiency of 17.46%. For higher efficiency of the peel, it is recommended to design a gasifier that would decrease the system heat loss and process the biomass into briquettes or pellets for a more uniform mass and size distribution.

Keywords: *renewable energy, gasification, biomass, banana peel*

INTRODUCTION

Banana (*Musa acuminata)* is a common plant in the Philippines that is mainly produced for food consumption, clothing, and export. The banana is a succulent herb that grows about 6-8 m high with a juicy "pseudo-stem". They are raised as monocrops depending on the consumers' preferences, location, and other climatic factors. Different varieties of bananas can be found in the Philippines, like cavendish, saba, latundan, lakatan, *senorita*, and others (Bergh, 2017). Cavendish banana has the biggest production (51.6%) followed by saba banana (28.0%), then lakatan (10.6%), and other varieties (9.8%) based on the Philippine Statistics Authority (2023) report for 2021. It was estimated that around 2.54 million metric tons of saba bananas were produced in 2021 and harvested from 186.57 thousand hectares of banana plantations and farms in the country. It was estimated in 2016 that an average Filipino consumes about 7.601 kg of saba banana for the whole year (Department of Agriculture High-Value Crops Development, 2018). In the production and post-production of bananas, it leaves a large volume of solid waste such as the rachis, leaves, and banana peel, which can be utilized in other forms (Acevedo et al., 2021). The peel is accounted for 18-33% of the waste product of banana production (Toh et al.,2016). This faces problems in waste management since the peel of saba is discarded after processing or cooking. The National Solid Waste Management Commission (2020) stated that characterizing the waste being disposed of, specifically its calorific value, is important in the establishment of waste-to-energy treatment technologies for effective waste management. To lessen the waste, the saba peel can be utilized as an alternative fuel that can be used for post-processing its main fruit.

One way of utilizing this agricultural waste is by treating it as a source of renewable energy. Kabenge et al. (2018) characterized banana peel waste as a potential biomass for slow pyrolysis. In their study, it has been found that the banana peel contains high amounts of fixed carbon and volatile matter which are needed for pyrolysis to yield quality produce. Gunaseelan (2004) subjected the peel to an anaerobic digester wherein it yielded the highest rate of methane production among other agricultural wastes.

When biomass is subjected to biological, chemical, or thermal change, it undergoes a reaction that would result as alternative fuels that can be used for heating. There are ways in extracting biomass such as anaerobic respiration, gasification, and pyrolysis. Among the three processes, anaerobic respiration does not require the material to be dried first, yet it is a biological conversion that utilize bacteria to convert the biomass into methane that would take weeks to yield the product. For thermal conversion, the material should be first be dried until its moisture content is less than 10% $_{db}$ (Abdullah, 2023). Pyrolysis is a process that applies heat to the feedstock with minimal or no oxygen in the chamber. In the process, it requires external heat to achieve certain temperature for the pyrolysis to happen. On the other hand, gasification is a thermal conversion that limits the oxygen to allow the production of synthetic gas (syngas) which are highly flammable (Ma et al., 2011). Compared to pyrolysis, gasification only requires small amount of external heat to burn the initial feedstock until the fire can sustained itself by using some of the syngas produced to act as fuel. Though in an updraft gasifier, additional energy is needed such as a blower to supply the proper amount of air to the chamber.

The process of gasification can be applied in cooking as it can act as a substitute for wood as fuel. In the study of Belonio (1989), he developed a gasifier stove using rice hull as feedstock that has a burning and thermal efficiency of 21% and 10%, respectively. In his study, the stove is more economical to use with payback period of 0.42, 1.3, and 3.5 years compared to electric, charcoal, and liquified petroleum gas (LPG) stove. Ale et al. (2009.)

assessed the fuel saved from using a fabricated gasifier (IGS-2F) compared to a traditional stove with a cost-benefit ratio of 4.0. They added that the payback period of the initial investment on the fabrication of IGS-2F is about 14 months. By developing a gasifier suitable for saba peel as feedstock, it would utilize the waste being thrown out and it can be more economical for banana vendors to use it as an alternative way of cooking their products.

Different factors affect the result of the gasification such as the type of gasifier used, the nature of the feedstock, and the air-to-fuel ratio. Basu (2010) enumerated that the design, quality of the biomass, airflow rate are some of the parameters that affects the efficiency of the gasifier. Solar Energy Research Institute (1988) stated that the application of the gasifier, logistical assessment, supply of feedstock, laws and regulations, and economic viability are some of the criteria that needs to be studied for the production of gasifier. In this study, a proto-type updraft gasifier was fabricated to subject the saba banana peel to gasification. By processing the saba banana peel using gasification, would lessen the waste in the crop postharvest processing and would serve as an alternate source of fuel for cooking or other agricultural applications such as drying.

This study aimed to test and evaluate the fabricated updraft gasifier utilizing saba banana peel as feedstock. Specifically, its objectives were to determine the selected physical and thermal properties of saba peel, design and fabricate an updraft gasifier, and evaluate the gasifier based on its thermal efficiency and equivalence ratio.

MATERIALS AND METHODS

Properties of Saba Banana Peel

The saba banana peel used was sourced from the waste of a local banana-cue vendor in front of Robinson's Mall, Los Baños, Laguna, Philippines. The selected physical (size, bulk density, and angle of friction) and thermal properties of the saba banana peel were determined. Solar Energy Research Institute (1988) requires the feedstock supply should be uniform in sizes for an efficient storage and gasification. In the study of Inayat (2016), they varied both the mixture and particle size of the coconut shell and wood chips into 0.5-1 cm, 1.0-2.5 cm, and 2.5-5 cm. They found out that the quality of syngas is affected by the particle size. For the study, the banana peels were chopped in different sizes (< 2cm, 2 cm-5 cm, and > 5cm) and were subjected to the oven drying process to generate a drying curve.

Samples of saba banana peel were dried and pulverized using a blender until it is finely ground. The heating value was tested at the Animal Nutrition Analytical Service Laboratory, Institute of Animal Science, College of Agriculture and Food Science, UPLB. For the Proximate analysis, the sample was analyzed by the Service and Testing Division, Industrial Technology Development Institute, Department of Science and Technology.

For gasification to occur, the theoretical air-to-fuel ratio for a complete combustion should be computed using the elemental composition of the feedstock specifically carbon, hydrogen, oxygen, and nitrogen. The equations of Parikh et al. (2007) use the fixed carbon percent and volatile matter content in predicting the percent values of C, H, and O. Nitrogen percentage can be assumed as the difference of 100% minus the C,H, and O. In using the equations, fixed carbon should be within 4.7-38.4 % and volatile matter in 57.2-90.6 % (De Oliveira et al., 2013). Using the equations of Parikh et al. (2007) (Equations 1 to 4), the elemental composition of the peel was predicted.

Parikh et al. (2007) Equations in predicting the C, H, O, and N of the peel

$$C: 0.637FC+0.455VM \qquad \textbf{Equation 1}$$
$$H: 0.052FC+0.062VM \qquad \textbf{Equation 2}$$

$O: 0.304FC + 0.476VM$ **Equation 3**

$N: 100\% - C - H - O$ **Equation 4**

where:

FC	is the fixed carbon, %
VM	is the volatile matter, %
C	is the carbon percentage, %
H	is the hydrogen percentage, %
O	is the oxygen percentage, %
N	is the nitrogen percentage, %

Equivalence Ratio (ER) is one of the main parameters that affect the temperature, composition, amount of syngas produced, heating value, and the tar produced. In the study of La Villeta et al. (2017), it states that ER ranges from 0.2 to 0.4 optimized both the amount of production and heating value of syngas. Different airflow rates would be used in the evaluation. For the calculation of the air to fuel ratio, and equivalence ratio, Equations 5 to 7 were used.

$$Air\ to\ fuel\ Ratio = \frac{Mass\ of\ air\ used, kg}{Mass\ of\ biomass\ consumed, kg}$$ **Equation 5**

$$Stoichiometric\ Air\ to\ Fuel\ Ratio = \frac{Amount\ of\ Air\ needed\ for\ combustion, kg}{mass\ of\ the\ biomass, kg}$$ **Equation 6**

$$Equivalence\ Ratio = \frac{Actual\ air\ to\ fuel\ ratio}{Stoichiometric\ Air\ to\ Fuel\ Ratio\ of\ complete\ combustion}$$ **Equation 7**

Design and Fabrication of the Prototype Gasifier

The design of the fabricated prototype updraft gasifier is presented in **Figure 1.** The physical properties of the saba peel were taken into consideration. The main parts of the gasifier are the hearth reactor, the air-flow system, the ash or char collector, and its body.

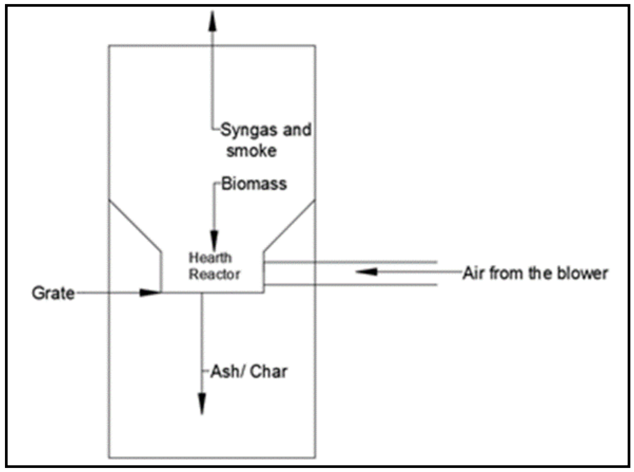

Figure 1. Schematic diagram of the prototype updraft gasifier.

A 5-inch diameter galvanized iron pipe and sheet were used as the body of the gasifier. The G.I. sheet was shaped into a cone to act as a hopper to the hearth reactor. A threaded GI cap was used to seal the gasifier for the exit of ashes. Perforated stainless steel with about 1/8-inch holes was added at the bottom of the reactor to prevent the biomass from falling.

To decrease the heat loss due to the conduction of the pipe, a throat was added to the design by reducing the diameter. The gap between the hearth and the outside pipe was filled with cement to insulate the hearth. The angle of the throat was set to 45º to permit the sliding of the peel to the hearth reactor.

A pan stay/ holder was placed at the top of the gasifier to put the container that was used for the boiling water test. Copper tubes were used to deliver the air from the thermal hose to the hearth reactor. A slot for a type K thermocouple was also added inside the reactor to monitor the temperature during the gasification process.

For the air inlet, a 400W commercial blower was used as the main tool for supplying air for gasification. A PVC pipe was used to deliver the air from the blower. Equivalence ratio is one of the factor that affects the efficiency of gasifiers. Basu (2010) stated that the equivalence ratio for gasification to be optimum is between 0.2 to 0.3. Three different airflow rates were used with a theoretical equivalence ratio of 0.2, 0.25, and 0.3. Twelve ¼ inch holes were punctured into the PVC pipe to reduce the flow of the air. The number of holes open served as the control for air that would be supplied. For the low airflow rate, all 12 holes were opened, for the medium airflow rate, 6 holes were opened, and for the high airflow rate, all 12 holes were closed. Two thermal hoses were used to connect the air system to the copper tube in the gasifier.

Gasification

In testing the gasifier, about 30g of saba banana peel was subjected to fire using a portable stove until it can sustain fire and was placed inside the gasifier. The blower is then turned on to supply the oxygen for the combustion of the saba banana peel. While burning, about 470g of saba banana peel was placed inside the gasifier. A burner was used to ignite the combustible gas produced. The time it took for the smoke to be ignited was measured. The pot containing the water was placed when the flame started to appear on top of the gasifier stove. Operation time was measured from the loading of the peel to the gasifier until the flame disappeared.

Starting temperature and maximum temperature of the water were measured using a mercury thermometer. The temperature inside the hearth reactor was measured using a type K thermocouple. In determining the heat produced during gasification, a boiling water test is conducted. Two liters of distilled water were placed in an aluminum pot to boil. The time, temperature and mass of water were recorded. Sensible heat, latent heat, total heat, and efficiency of the water were calculated using Equations 8 to 13, respectively.

$$M_E = M_{wi} - M_{wf} \quad \textit{Equation 8}$$

$$SH = M_w * Cp * (T_{final} - T_{inital}) \quad \textit{Equation 9}$$

$$LH = M_E * LHV \quad \textit{Equation 10}$$

$$Total\ heat\ used = SH + LH \quad \textit{Equation 11}$$

$$Heat\ produced\ by\ fuel = HV * mass\ of\ fuel\ burned \quad \textit{Equation 12}$$

$$Efficiency = \frac{Total\ heat\ used}{Heat\ produced\ by\ fuel}\ x100\% \quad \textit{Equation 13}$$

where:

M_E is the mass evaporated, kg
M_{wi} is the initial mass of water, kg
M_{wf} is the final mass of water, kg
SH is the sensible heat, kJ
LH is the latent heat, kJ
M_w is the mass of water used, kg
$T_{initial}$ is the initial temperature of the water, °C
T_{final} is the final temperature of the water, °C
LHV is the latent heat of vaporization, 2,257.03 kJ/kg
Cp is the specific heat of water, 4.19 kJ/kg
HV is the heating value, 18778 Kj/kg

One-way Analysis of Variance with a 0.05 level of significance was used in determining if there are significant differences in the airflow rates and sizes of the biomass to the computed efficiency and equivalence ratio.

RESULTS AND DISCUSSION

Physical and Thermal Properties of Saba Banana Peel

The initial average moisture content of fresh saba banana peel is approximately 83.12 %. Samples used in the testing were dried for at least six hours and had an average moisture content of 8.52 %. Selected physical properties of saba were tabulated in **Table 1**. The average size of banana peel was 1.66 cm for small-cut size, 4.02 cm for medium-cut size, and 7.53 cm for large-cut size. For the angle of friction, the average angle measured was 37.07˚. For bulk density, the average was 0.243 g/cc wherein peels >5 cm has the highest with an average of 0.26 g/cc. A drying curve was generated as shown in **Figure 2**. Using one-way ANOVA, there is no significant difference in the selected size of the saba banana peel on the difference of the moisture content of the peels during drying.

The obtained gross energy or heating value of the saba banana peel is approximately 18.78 MJ/kg. When compared to the heating value of the coal which is approximately 35.01 MJ/kg (Raveendran & Ganesh,1996), the saba banana peel can yield up to 53.64% of the coal's total heating value. Other thermal properties of saba peel were also obtained yielding 10.1% for moisture content, 10.3% for ash content, 20.7% for fixed carbon, and 69.0% for its volatile matter. Volatile matter and fixed carbon content influence the heating value of biomass (Speight, 2015). In addition, higher volatile matter means the biomass is good to be subjected to gasification or pyrolysis while higher fixed carbon content means the biomass is good for char production. A high heating value and high volatile matter content suggest that the saba banana peels are of good potential as biomass to be subjected to gasification.

Table 1. Selected physical properties of saba banana peel.

AVERAGE PHYSICAL PROPERTIES	<2 CM	2 CM - 5 CM	>5 CM
Length (cm)	1.66	4.02	7.53
The angle of Friction (˚)	34.19	37.34	39.28
Bulk Density (g/cc)	0.26	0.25	0.22

The heating value and proximate analysis results of the saba banana peels were compared with other biomass that was obtained from studies by Jenkins et al. (1998) and Di Nola et al. (2008) as shown in **Table 2**. The heating value of the saba banana peel is relatively close to the sugar cane and alfalfa stem while it is relatively higher to rice hull, straw, and corn residue which are the common crops in the Philippines. The results in the volatile matter and fixed carbon content are in agreement with the literature of Speight (2015) which states that higher volatile matter means the biomass is good to be subjected to gasification or pyrolysis while higher fixed carbon content means the biomass is good for char production. A high heating value and high volatile matter content suggest that the saba banana peels are of good potential as biomass to be subjected to gasification.

The obtained thermal properties of saba were used in the computation for predicting

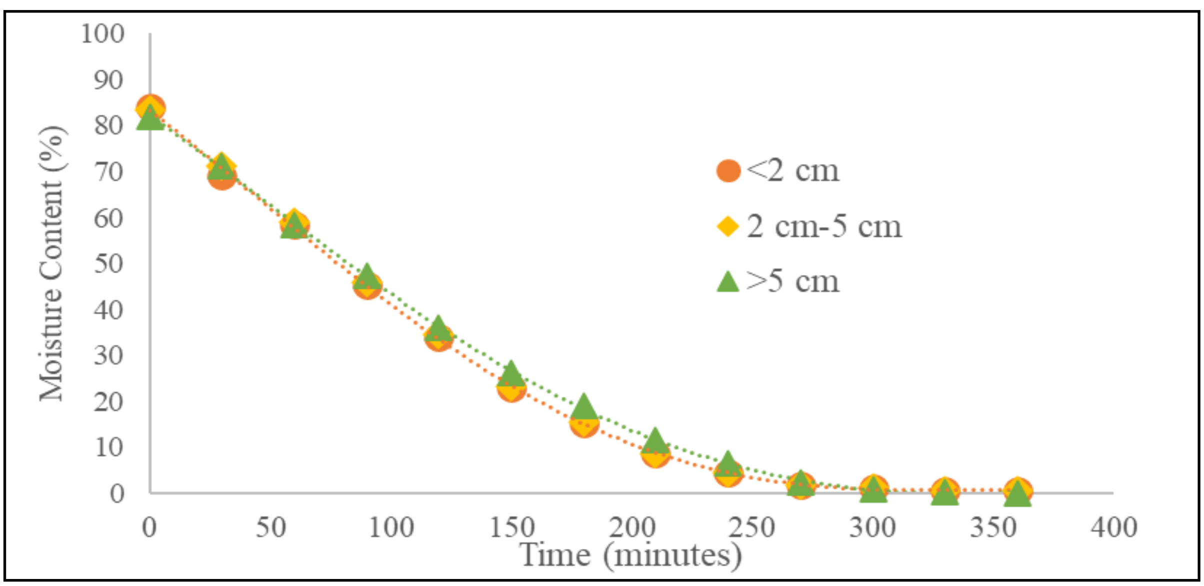

Figure 2. Drying curve of saba banana peel.

elemental composition using the equations of Parikh, et al. (2007). The computed elemental composition yielded 18.24 MJ/kg with a percent error of 2.84 % using the Boie Equation in comparison with the actual heating value. By using the balanced equation (Equation 18), the theoretical air-to-fuel ratio for combustion is approximately 6.92 kg air per kg biomass.

Gasification of Saba Banana Peel

The fabricated prototype was tested as a gasifier stove with the saba banana peel used as its fuel (**Figure 3**). Around 500g of saba peel was used per test which took about 30 minutes per run. The airflow rates of the air used per test are 1.19, 1.47, and 2.07 kg/h that has an average air-to-fuel ratio of 1.28, 1.67, and 2.21 respectively. A lower air-to-fuel ratio compared to the ratio for combustion would permit for gasification to take place and to produce synthetic gas (syngas), a mixture of hydrogen gas and carbon monoxide that are the main products for gasification.

During gasification, the fire on top was observed. Gasification using a high airflow rate setting yielded a larger fire while a lower flow rate setting yielded a smaller fire (**Figure 4**). It was also observed that the color of the fire was purple to red for medium and low flow rates. Smoke during gasification was minimal yet before the ignition of the gas, a large amount of smoke was coming from the gasifier.

$$C_{3.71191}H_{5.29703}O_{2.44625}N_{0.780157} + 5.03617(O_2 + 3.76\ N_2) \rightarrow 3.71191CO_2 + 2.64851H_2O + 5.1399(3.76N_2) \qquad \textit{Equation 18}$$

Table 2. Heating value and proximate analysis of different biomass.

BIOMASS	HEATING VALUE (MJ/KG)	FIXED CARBON CONTENT (%)	VOLATILE MATTER CONTENT (%)	ASH CONTENT (%)
Rice Straw	15.09	15.86	65.47	18.67
Rice Hull	15.84	16.62	63.52	20.26
Yard Waste	16.3	13.59	66.04	20.37
Wheat Straw	17.94	17.71	75.27	7.02
Switchgrass	18.02	14.34	76.69	8.97
Alfalfa Stem	18.67	15.81	78.92	5.27
Almond hull	18.89	20.07	73.8	6.13
Sugar Cane	18.99	11.95	85.61	8.97
Willow Wood	19.59	16.07	82.22	1.71
Fir Mill	20.42	17.48	82.11	0.41
Mixed Paper	20.78	7.42	84.25	8.33
Corn Residue	15.0	19.3	73.1	7.6
Palm kernel	17.9	17.6	76.9	5.5
Chicken Litter	8.78	4.6	35.4	12.5
Saba banana peel	18.78	20.7	69.0	10.3

Source: Jenkins et, al. 1998 and Di Nola et al. 2008

Figure 3. The fabricated prototype updraft gasifier.

Figure 4. Size of the flame in low(left), medium(middle), and high(right) air flow settings.

The time of the ignition suggests that the ignition temperature has been achieved during the process. Ignition temperature is a property of the fuel wherein it needs to achieve to have combustion and can sustain the flame. An average of 5.36 minutes was calculated for the smaller sizes while the 2 cm to 5cm has an average of 7.86 minutes, and lastly for the largest sizes has an average of 8.77 minutes. For the hearth reactor, the temperature was recorded and graphed in **Figures 5, 6, and 7**. For the gasification of > 5 cm, it can be observed that for high flow rate reaches only a maximum temperature of about 332º C at around 4 minutes of the operation. The medium flow rate and low flow rate achieved a maximum temperature of 529.2 and 431.5 º C respectively. For 2 cm—5 cm, a high flow rate also yielded the lowest temperature during operation of 458.0 º C compared to the medium and low flow rates of having 632.21 º C and 668.5 º C respectively. For < 2 cm, it is the high flow rate that has the lowest temperature of 476.3º C among the other flow rates while the medium and low flow rate has 620.75º C and 642.3º C respectively. The low maximum temperature of the hearth during gasification using the high flow rate setting can be due to the air inlet affecting the reading of the thermocouple since high flow rate can decrease the temperature inside.

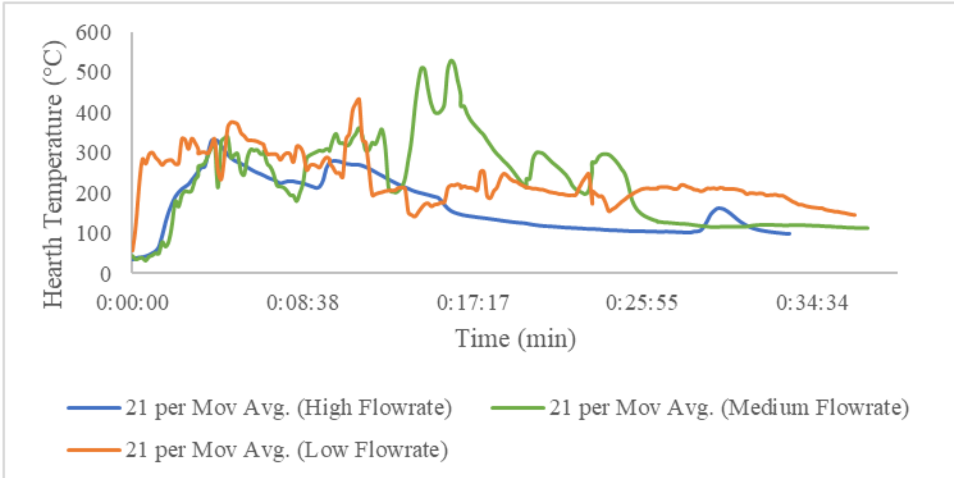

Figure 5. Hearth temperature for sizes greater than 5 cm during gasification.

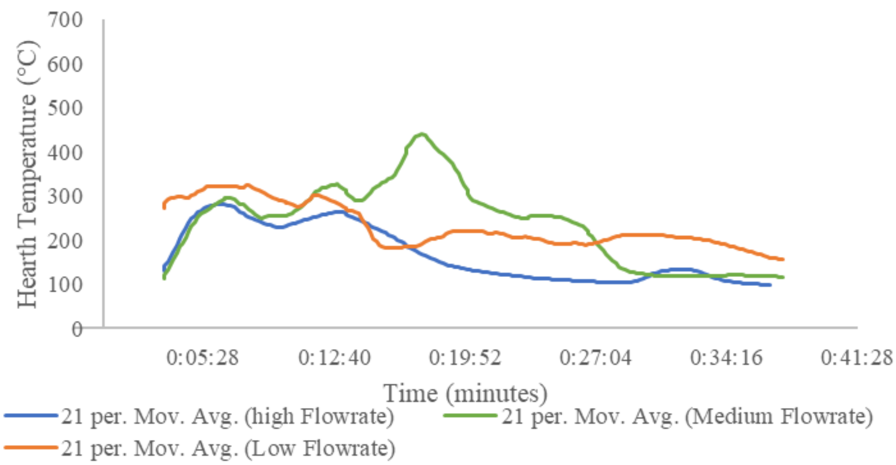

Figure 6. Hearth temperature for sizes from 2 cm to 5 cm during gasification.

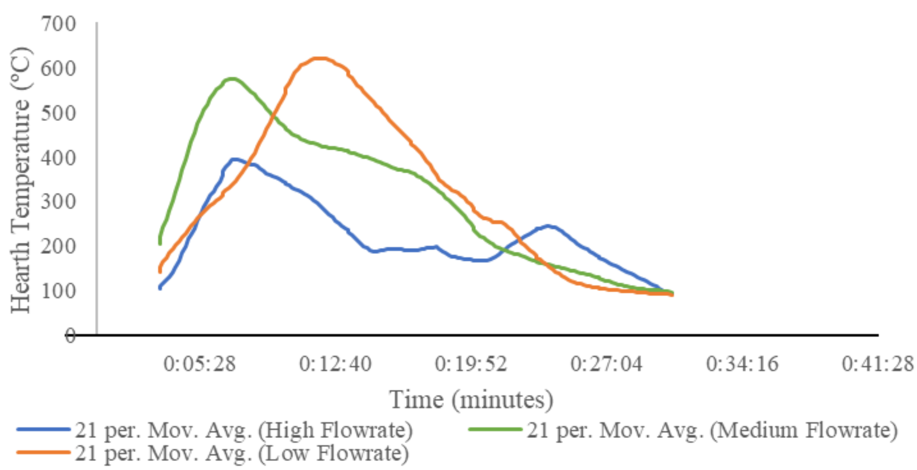

Figure 7. Hearth temperature for sizes less than 2 cm during gasification.

The amount of heat produced, burning rate, biomass input, efficiency, air-to-fuel ratio, and equivalence ratio were tabulated in **Table 3 to Table 5.** The efficiency of the gasifier ranges from 10% to 18%, with an average of about 15.21%. High efficiency was observed using low airflow rate settings. Low thermal efficiency can be caused by heat loss during the test. Losses of heat from the burner to water were influenced by the convection and radiation from the burner to the surrounding since the system is not closed and is highly insulated.

Table 3. Parameters on the gasification of <2 cm saba banana peel.

AIR FLOW (kg/h)	1.19	1.47	2.07
Heat produced (kJ)	1420.82	1556.83	1318.16
Burning rate(kg/h)	1.0289	1.0705	1.0007
Biomass input (kJ)	8776.84	9048.18	8891.38
Efficiency	16.19%	17.21%	14.83%
Actual air to fuel	1.159	1.377	2.066
Equivalence Ratio	0.170	0.199	0.299

Table 4. Parameters on the gasification of 2 cm – 5 cm saba banana peel.

AIR FLOW (kg/h)	1.19	1.47	2.07
Heat produced (kJ)	1534.85	1315.49	1172.86
Burning rate(kg/h)	0.9638	0.8946	0.9004
Biomass input (kJ)	8898.89	8866.03	8923.31
Efficiency	17.25%	14.84%	13.14%
Actual air to fuel	1.238	1.648	2.296
Equivalence Ratio	1.789	0.238	0.332

Table 5. Parameters on the gasification of > 5 cm saba banana peel.

AIR FLOW (kg/h)	1.19	1.47	2.07
Heat produced (kJ)	1562.63	1370.6	962.587
Burning rate(kg/h)	0.827	0.8113	0.9136
Biomass input (kJ)	8949.59	9097	8813.45
Efficiency	17.46%	15.07%	10.92%
Actual air to fuel	1.442	1.817	2.262
Equivalence Ratio	0.208	0.262	0.327

Using One-Way ANOVA, it was found out that the sizes of the cut of peel did not significantly affect equivalence ratio and thermal efficiency of the gasifier. The burning rate is also relatively lower for peels with sizes >5 cm. Though during gasification, large peels often clump up at the top of the hearth reactor. With this, the biomass needs to be poked so that the unburnt biomass would flow toward the reactor. Caking or the clumping up of biomass is the result of unburnt char and ash formed at the top of the hearth reactor creating a barrier preventing the flow of biomass (Speight, 2015). The size of the biomass did not significantly affect the result of the equivalence ratio.

On the other way around, varying the airflow during gasification had a significant difference on the calculated equivalence ratio wherein as the flow rate decreased, the equivalence ratio also decreases. Equivalence Ratio (ER) is the ratio of the actual air-to-fuel ratio over the stoichiometric air-to-fuel ratio for combustion with a gasifier should have ER of 0.2-0.3 (Basu, 2010). He stated that ER less than 0.25 for an updraft gasifier would have higher tar content, while above 0.25 would produce more syngas that would be burn thus, increasing the temperature. Since all the ER of the tests are below one, it means that gasification occurs on every test. The calculated ER ranges from 0.17 to 0.33 wherein data with a flowrate of 2.07 kg/h and 1.47 kg/h agrees with the study of La Villeta (2017) which states that ER ranges from 0.2 to 0.4 optimize both the amount of production and heating value of syngas.

The calculated ER from the tests ranges from 0.17 to 0.33 (**Figure 8**) wherein data with a flow rate of 2.07 kg/h and 1.47 kg/h agrees with the study of La Villeta (2017). The highest heat produced by the gas is around 1,500kJ at an equivalence ratio of around 0.21. An equivalence ratio lower than 0.21 has declined the produced heat as shown in **Figure 8**. It was observed during the gasification when the equivalence ratio increased the heating value of the produced gas decreased. The decrease in the ER lower than 0.21 can be interpreted that the gasification produced more tar than syngas (Basu, 2010). Basu (2010) stated that higher ER could have excessive formation of CO_2 and H_2O as product of a complete combustion. For ER of about 0.30, perfect combustion may took place thus, lowering the heat produced of the gasifier.

Using Two-way analysis of variance (ANOVA) on the efficiency of the gasifier, significant difference was only observed in varying the airflow rate affecting the thermal efficiencies of the gasifier. By increasing the airflow rate of the gasifier, equivalence ratio also increases. La Villeta (2017) stated an increase in ER would yield lower heating value, because of the decrease of CO and H2 production and increase of tar formation in the gasifier. Efficiency of the gasifier is more sensitive to the airflow rate heavily affecting the heat produced by the feedstock.

CONCLUSION AND RECOMMENDATION

With thermal properties of 18.78 MJ/kg, the saba peel can be utilized as an alternative fuel by gasification. The elemental composition was determined using Parikh et al. (2007) equation and yielded an air-to-fuel ratio of 6.92 $kg_{air}/kg_{biomass}$. Lower air-to-fuel ratios were used to permit gasification during testing. A proto-type updraft gasifier was fabricated to subject the peel to gasification. During gasification, the size of the peel did not affect both the thermal efficiency of the gasifier and the equivalence ratio, but it influenced the ignition time and burning rate. On the other hand, the airflow rate influenced the thermal efficiency and the equivalence ratio. The thermal efficiency of the gasifier yielded less than 20% due to heat loss during gasification. Losses of heat from the burner to water were influenced by the convection and radiation from the burner to the surrounding since the system is not closed. The equivalence ratio was calculated ranging from 0.17 to 0.33 and influences the heat produced. An equivalence ratio of around 0.21 yielded the highest heat produced by the syngas.

The application of gasification of saba banana peel can be utilized as the heat source for fruit dryers or dehydrators for processing banana chips. The gasifier can also be re-design such that it can be used for cooking. Saba peels as

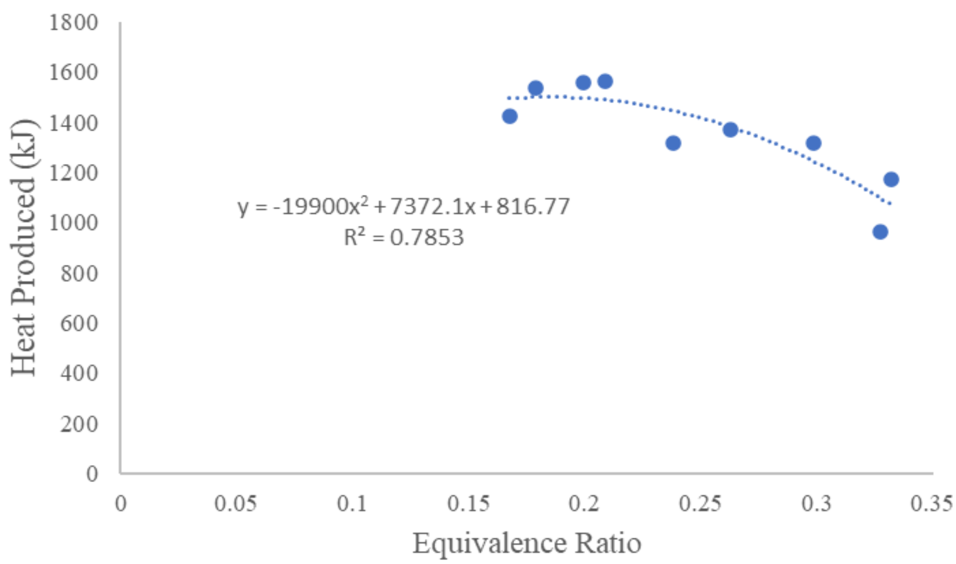

Figure 8. Relationship of heat produced and equivalence ratio.

an alternative source of fuel can help local farmers/ manufacturers to lessen their fuel consumption in processing the main fruit.

For further studies, it is recommended to design a gasifier that would decrease the heat loss in the system. It is also recommended to process the saba banana peel into briquettes or pellets for a more uniform mass and size distribution for easier handling and processing as energy feedstock. Lastly, it is recommended to conduct financial analysis on the development of a gasifier using saba banana peel as its feedstock. It is vital to study the economic viability and cost-benefit ratio on the development of a gasifier stove and to compare its effectiveness and yield to other waste-to-energy conversion such as anaerobic respiration and pyrolysis.

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