Design and Development of a Wood-Fired Gasifier Prototype for Synthesis Gas Production and Analysis

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Abstract -*Synthesis gas formation which can be transformed to useful compounds through biomass gasification is perceived as one promising process of biofuel production. A construction, design and development of an efficient and small-scale wood-fired gasifier prototype was made at Batangas State University. This study included the costs and specifications of materials, the design, components and percent conversion of the biomass to syngas by obtaining the amount of the residue. Set of operating conditions were determined so as to achieve a good performance of the gasifier; otherwise it adversely affected the operation of the prototype. The gasifier operates in a condition in which the air flow rate is 560 - 610 cm^3/min wherein the valve is half-open and the blower is turned on after 20 seconds. The gasifier will be closed after a minute of start-up. With these conditions, the gasifier works accordingly to a smooth operation. Syngas was composed of methane (2.32 % volume), carbon dioxide (10 % volume), carbon monoxide and minimal amount of hydrogen. Two (2) kg of woodchips with 90.75% conversion was the best amount of feed suited for the operation of the gasifier. This innovation comprises a method which efficiently converts the feedstock thereby enhancing the energy of the syngas produced with by-products at minimum acceptable value. The wood-fired gasifier will be a very helpful tool in contributing to the resolution of pressing social and environmental problems such as energy security and local agricultural waste pollution.*

Keywords - *Biomass gasification, Biofuel production, Energy security, Synthesis gas, Wood-fired gasifier*

INTRODUCTION

Fossil fuel resources are gradually decreasing causing the cost of petroleum-based products to increase. This problem imposes a need for an equipment that can produce an alternative source of fuel.

Gasification is a process for converting carbonaceous materials to a combustible or synthetic gas [1]. In general, gasification involves the reaction of carbon with air, oxygen, steam, carbon dioxide, or a mixture of these gases at 150°C to 700°C or higher to produce a gaseous product [2].Gasification technology has been widely used to produce commercial fuels and chemicals. Current developments in the chemical manufacturing and petroleum refinery industries show that use of gasification facilities to produce synthesis gas will continue to rise. A striking feature of the technology is its ability to produce a reliable, high-quality syngas product that can be used for energy production or as a building block for chemical manufacturing processes [3].

Synthesis gas or syngas, which is the direct end-product of the gasification process, is defined as a gas that contains H_2 and CO as main combustible components. Raw syngas mostly inevitably contains also considerable amounts of CO_2 and H_2O [4].Though it can be used as a standalone fuel, the energy density of syngas is only about 50 percent that of natural gas and is therefore mostly suited for use in producing transportation fuels and other chemical products. As its unabbreviated name implies, synthesis gas is mainly used as an intermediary building block for the final production of various fuels such as synthetic natural gas, methanol and synthetic petroleum fuel [5].

To provide means of constructing an efficient and small-scale equipment used for gaseous fuel production, the researchers have come up to design and develop a wood-fired gasifier prototype. This equipment is a device which consists mainly of a cylindrical container, a reactor chamber and a gas exit. The innovation comprises a method which efficiently converts the feedstock thereby enhancing the energy of the syngas produced with by-products at minimum acceptable value.

The wood-fired gasifier will be a very helpful tool in contributing to the resolution of pressing social and environmental problems such as energy security and local agricultural waste pollution. Therefore it will provide a way to conserve and save the environment and bring home green energy to its fullest.

OBJECTIVES OF THE STUDY

The study was envisioned to design a prototype which was used for syngas production and analysis. Specifically, the research aimed to: design and develop a wood-fired gasifier prototype taking into account the following: gasifier components and material requirements and specifications; conduct pilot testing to establish the best operating condition of the gasifier using different amounts of feed (1, 1.5 and 2 kg) of palo china woodchips in terms of the following: Air flow rate, Time of turning on the blower, and Time of closing the cover to minimize heat losses; evaluate the composition of the syngas in terms of %volume: CO_2; CH_4; CO, and H_2 ; determine the best amount of feed using the established operating condition that will show a good performance of the gasifier based on percent conversion of biomass to syngas by obtaining the amount of the residue; and provide a manual for the operation of the gasifier.

MATERIALS AND METHODS

This study was a project development with experimental method of research. It was composed of three parts which are the design and development of a small-scale gasifier prototype for syngas production on a batch process, collection and evaluation of the syngas in terms of percentage composition and evaluation of the gasifier performance by computing the percent conversion of the wood into syngas.

The completion of the study was based on the design and development process, fabrication and assembly, and testing and evaluation.

Gasifier Prototype Design

The gasifier prototype is capable of converting palo china woodchips into synthesis gas. The desired amount of feed is loaded in the reaction chamber and fired before the blower is turned on. The cover is closed at the minimum possible time when combustion reaction proceeds. A thick white smoke is produced in the flare tower that when ignited produce stable flame [6]. This is a physical indication of synthesis gas.

Figure 1 illustrated the project design and its parts that the researchers followed in the fabrication and assembly of the prototype.

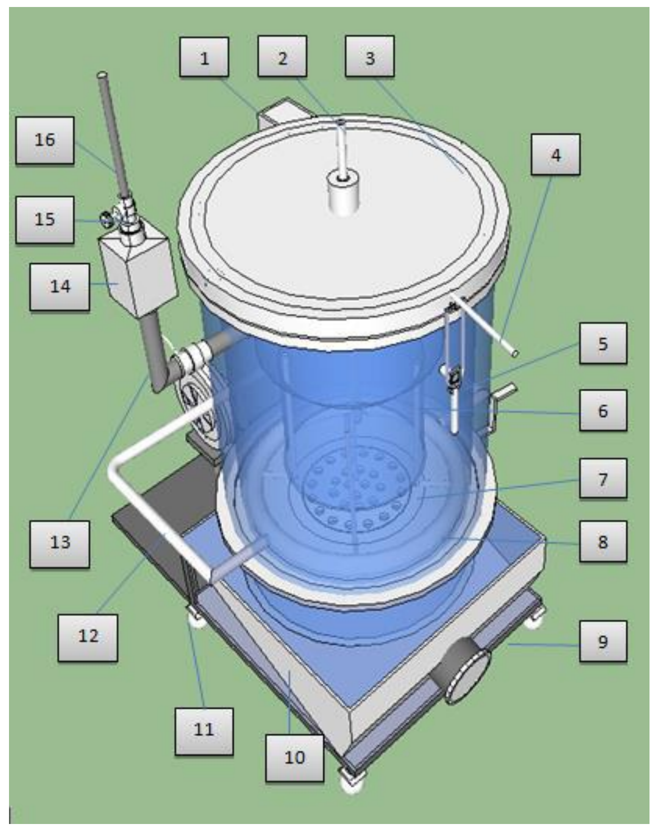

Figure 1. Isometric view of the Gasifier and its Parts

(1) Temperature Indicator Box (2)Stirrer (3) Cover (4) Handle (5) Clamp (6) Nozzle (7) Grate (8) Manifold (9) Char Nipple Outlet (10) Char Pan (11) Roller (12) Gas Pipe
(13) Blower (14) Filter (15) Syngas Controller (16) Syngas pipe/flare tower

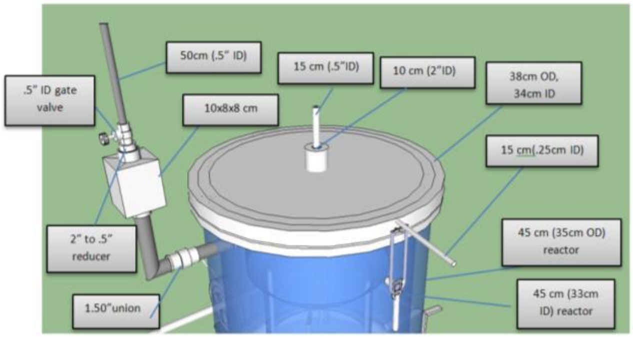

Figure 2. Gasifier Upper Assembly

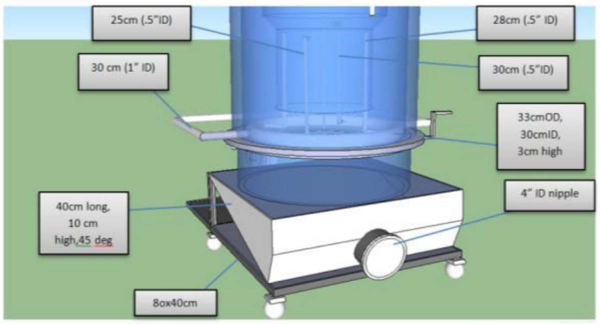

Figure 3. Gasifier Lower Assembly

Equipment Fabrication and Assembly

The prototype was fabricated and assembled at G – Force Engineering and Machine Shop located at Malvar, Batangas.

The layout of the chambers, fuel hopper, inner and outer cylinder, and gas pipe of the gasifier was prepared. The main body of the gasifier was made up of stainless steel and was divided into two sections. These sections were the top cylinder (reaction chamber) and bottom cylinder (ash chamber). These chambers have the same inner diameter and outer diameter [7].

The middle part or reaction chamber was the heart of the gasifier where the syngas is produced [7]. Fuel flows down by gravity. There are four pipes connected to the manifold, two of which are perforated and the other two are open ended. Flanged at the top and bottom of both cylinders were welded to minimize the leak. The chamber was also consisted of mechanical guide.

The bottom cylinder or ash chamber contained the ash zone where the ash resulting from the gasification process of the biomass was stored and occasionally removed [7]. The ash from the reaction chamber could fall down freely through the grate. Below the cylinder was the char deposit.

Primary air in the oxidation zone was supplied by four air inlet nozzles placed in the middle of the reaction chamber. These nozzles were connected to the round shaped primary air inlet manifold placed around the middle cylinder [7]. The manifold was constructed of round mild steel pipes.

A flare tower made up of pipes of decreasing diameter was added as gas outlet. The filter can be attached to the gas outlet to remove the suspended particulate. Finally, four small wheels was installed at each side of the bottom of the gasifier for easy movement to a suitable place for testing and use.

General Operation Procedure

In order to achieve the desired performance of the machine, it should be operated properly. Care must be done since the prototype used mechanical parts that could hurt the user.

a. Properly check the gasifier. Make sure that the fan is functioning well when turned ON and shuts down properly after turning it OFF.
b. Set the blower making it half-open.
c. Mix the woodchips and wood shavings with following ratio depending on the desired amount of the feed:
   1kg mixture: 950g woodchips and 50g wood shavings
   1.5kg mixture: 1425g woodchips and 75g wood shavings
   2kg mixture: 1900g woodchips and 100g wood shavings
   Make sure that wood shavings are distributed for easy start-up.
d. Place the desired amount of the mixture in the gasifier.
e. Lit the wood shavings with the gas range lighter.
f. After 20 seconds, turn ON the fan.
g. After1 minute carefully close the gasifier. Quickly place the stirrer followed by the thermocouple.
h. Monitor the temperature inside the reactor chamber. Take note that the temperature should be above 260˚C to assume the presence of syngas.
i. When the temperature has reached 260˚C, a thick white smoke can be observed which is an indication of syngas. To further check the syngas, lit the thick white smoke with the gas range lighter. A flame in the flare tower signifies the presence of the syngas.
j. Measure the temperature of the syngas using the Extech 42510 wide range Mini IR Thermometer.

k. Monitor the temperature; take note of the maximum temperature that the gasifier can reach. When a decrease in temperature was observed, wait until it reaches 260˚C before checking again for the syngas.
l. When there is no more syngas observed, turn off the blower and allow the prototype to stand for cooling for at least 30 minutes.
m. Discharge the char, collect and weigh.

RESULTS AND DISCUSSION

The materials used and cost estimation, the design specifications and main components in the fabrication and assembly of the wood-fired gasifier prototype is included here. The performance of the gasifier based on percent conversion of biomass to syngas by obtaining the amount of the residue is also presented.

Gasifier Components

The gasifier parts include the temperature indicator box, stirrer, cover, handle, clamp, nozzle, grate, manifold, char nipple outlet, char pan, roller, gas pipe, blower, filter, syngas controller, syngas pipe/flare tower.

Material Specifications

Table 1. Material Specifications of the Main Gasifier

Parts	Dimension	Materials of Construction
Reactor Chamber	39cm, 27cm ID	Stainless steel
Column	45cm, 35cm ID	Stainless steel
Flaring Tower	50cm, 0.5” ID	Stainless steel
Filter Box	10cmx8cmx8cm	Stainless steel
Pipes	1 ½”, sch. 40	Stainless steel
Gate Valve	½” ID	Galvanized Iron
Union	1 ¼” ID	Galvanized Iron
Nipple	2” sch.40 4” sch. 40	Galvanized Iron
GI Cup	2” OD	Galvanized Iron
Grate	28cm	Stainless steel
Check Valve	1.5”	Galvanized Iron
Rod	20”, ¼ OD solid	Stainless steel
Nozzles	28cm, 0.5” ID	Stainless steel
Inclined Char Pan	40cmx40cmx10cm	Stainless steel
Support Plate	60cmx40cm	Cast Iron

Table 2. Material Specification of the Auxiliary Device

Parts	Capacity
Blower	3000/3600rpm, 1A, 50/60cycles
Thermocouple	- 200˚C - 650˚C
Probe	- 250˚C - 899˚C

The maximum capacity of the developed gasifier was 2kg. Height of the column was 45cm and has a 35 cm inside diameter column. The dimensions of stainless reactor chamber inside the column were 39cm in height and 27cm inside diameter. Four nozzles (½” ID), two of which were perforated at the side, were connected to the manifold located inside the reactor chamber. The stainless steel flaring tower which was 50cm in height and had ½” inside diameter with ½” gate valve was connected to the filter box (10cm x 8cm x 8cm).

The said assembly was connected to reactor chamber using 1 ¼” ID union. Union was used as a connector for easy removal of clogs, particularly soot, tar and condensate. Supplying the air needed for gasification, Lotus centrifugal blower having 3000 - 3600 rpm, operating at 1A was used. This was connected to the manifold by 1 ½”, sch. 40 stainless steel pipe located at the back side of the prototype. A 1 ½” galvanized iron check valve was used to prevent the back flow of the syngas to the blower. A 28cm diameter stainless steel perforated plate was used as grate. A 45° inclined char depositor was located underneath the reactor chamber. A 4” sch. 40 nipple was used as cover to the char depositor to prevent leaks. For monitoring of temperature, thermocouple was used. Solid rod, 20in long, was utilized to stir the feed inside the reactor chamber.

Cost Tabulation of the Gasifier Prototype

The cost of materials and equipment used in the fabrication was tabulated on the following table.

Table 3. Cost of Materials and Miscellaneous Items

Item	Qty	Unit	Price	Cost
Stainless Steel	2	Sheets	P3,500.00	P7,000.00
Pipes (1 ½ sch.40)	1	pc.	500.00	500.00
Gate Valve (½)	1	pc.	300.00	300.00
Union (1 ¼ ID	1	pc.	64.00	64.00
Niple (2” sch.40)	1	pc.	68.00	68.00
Oil Seal	2	pcs.	90.00	180.00
GI Cup (2” OD)	1	pc.	50.00	50.00
Check Valve (1.5” GI)	1	pc.	400.00	400.00
Rod (20”, ¼ OD, solid)	1	pc.	35.00	35.00
Teflon	5	pcs.	15.00	75.00
Gaskets (18”x18”)	1	pc.	260.00	260.00
Cord Epoxy Steel (40g)	1	pc.	95.00	95.00

Table 3 (cont). Cost of Materials and Miscellaneous Items

Item	Qty	Unit	Price	Cost
Lighters	5	pcs.	25.00	125.00
Lighter Refill	1	pc.	100.00	100.00
Blower	1	pc.	1,500.00	1500.00
Thermocouple (Sensor Type, Type K)	1	pc.	1,689.00	1,689.00
Temperature Indicator	1	pc.	2,500.00	2500.00
Wood	200	Kilos	2.50	500.00
Syngas Analysis	2	Tests	3,150.00	6, 300.00
Fabrication	-	-	15,000.00	15,000.00
Modification	-	-	5600.00	5,600.00
Miscellaneous	-	-	5,000.00	5,000.00
GRAND TOTAL			**P 47, 341.00**	

Preliminary Testing

Preliminary testing was done to establish the best operating condition of the gasifier

Time of Turning on the Blower

To assist in the start-up of the combustion process**,** proper timing on turning on the blower was established.

Table 4. Time of Turning on the Blower

Time (sec)	Observations
10	Flame did not continue
15	Flame continue slightly but went off easily
20	Flame continued

The tabulated result was based upon the observation using the different weights of wood (1kg, 1.5kg, 2kg). From the observations, it can be concluded that the 20 seconds time span after start-up was the best condition in turning on the blower.

Air flow rate, Blower condition and closing time of cover

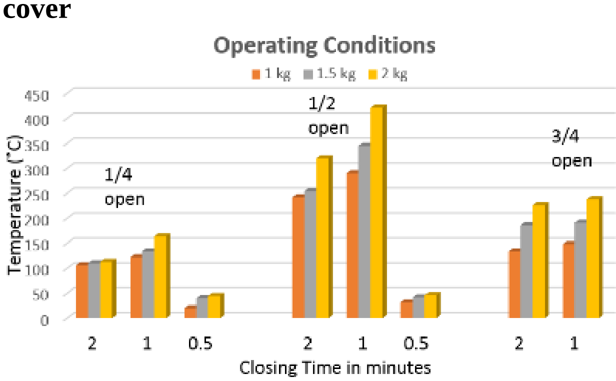

Figure 4. Establishing the operating conditions

The air flow rate, blower percentage opening and the closing time in minutes are the operating conditions that also needs establishment. On the left column was the maximum temperature reached at the 10 minute time span from the start-up.

The analysis is shown in figure 4.

Based on the graph, using 1kg, 1.5 kg and 2kg woodchips, it was clearly shown that maximum temperatures inside the reaction chamber were noted when the blower was half-open which has a 560 - 610 cm^3/min air flow rate. This relationship was shown based on the principle that when the temperature increases, there will be a continuous gasification of the woodchips inside the gasifier. Between 1 kg, 1.5kg and 2 kg of woodchips, the latter showed higher temperature than the other two amounts giving a conclusion that 2 kg is best to use as the amount of feed.

It was evident that closing the gasifier one minute after firing the feed was just enough to keep the combustion process inside. With this condition, heat loss was minimized and the highest temperature was attained.

Gasifier Performance

The percent conversion of the gasifier was calculated based on the amount of feed and the amount of the char collected after gasification. The formula used was:

$$\%\ conversion = \frac{mass\ of\ feed - mass\ of\ residue}{mass\ of\ feed}\ x\ 100$$

Table 5. Actual Testing Result

OPERATING CONDITIONS:			
Air flow rate:	*560 - 610 cm^3/min*		
Opening time of blower:	*20 sec*		
Closing time of cover:	*1 min*		
	1 kg	1.5 kg	2 kg
Maximum Temperature Reached (°C)	290	355	421
Syngas Duration (min)	10	37	48
Mass Of Coal Recovered	736	220	185
% Conversion	26.4	85.33	90.75

Table 5 shows the actual testing result with the established parameters.

It was observed that as the amount of wood increases, the maximum temperature reached increases as well as the duration of the syngas. Also, as the temperature increases, the amount of coal recovered as ash decreases, thereby enhancing the percent conversion of the gasifier.

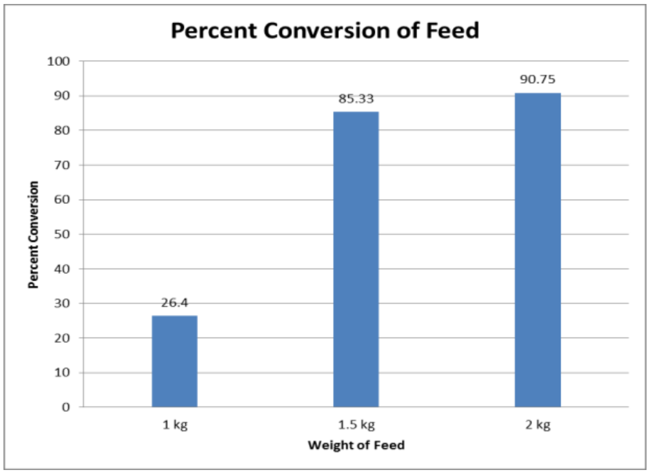

Figure 5. Percent conversion of the feed

According to the graph, 2 kg of woodchips showed a high percent conversion of 90.75%. Together with the established operating conditions, it was clear that when the amount of feed increases, the amount to be gasified also increases.

Evaluation of Syngas Produced

The composition of the syngas was determined using Gas Chromatography conducted by the Department of Energy (DOE) for %CH_4 and %CO_2. The analysis resulted to 10% CO_2 and 2.23% CH_4 which conforms to the reference composition of 5-10% CO_2 and 1-5% CH_4 [8].

Carbon monoxide was detected using the Extech Combustion Analyzer (Bacharach PCA3). During the testing, the reading showed an error value which indicated that the actual composition of CO exceeded the maximum capacity of the equipment which is 999 ppm.

For the H_2 content of the syngas, qualitative test was used. For this test, a popping sound will indicate the presence of hydrogen. This sound was formed by the burning of hydrogen with oxygen. In using this test, there was an irregular observation on that popping sound. Therefore, minimal amount of hydrogen was present.

CO and H_2O was said to be the mixture present in the remaining percentage composition of syngas.

CONCLUSION

The gasifier components, material requirements and the design specifications were met in designing and developing the wood-fired gasifier prototype.

The best operating condition of the gasifier are as follows; air flow rate must be560 - 610 cm^3/min, turning on the blower is 20 seconds after firing the feed and closing the cover after 1 minute.

The produced gas was synthesis gas since the compositions of it such as CO_2 and CH_4 met the standard reference. The remaining percentage of syngas was composed of CO and minimal amount of H_2.

Highest percent conversion of biomass to syngas was achieved using 2 kg of palo china woodchips with the established operating conditions as the best amount of feed suited for the operation of the gasifier.

The proper way of operating the gasifier is described in the following ways:

a. Properly check the gasifier. Make sure that the fan is functioning well when turned ON and shuts down properly after turning it OFF.
b. Mix the woodchips and wood shavings with following ratio: 1900g woodchips and 100g wood shavings. Make sure that wood shavings are distributed for easy start-up then place the mixture in the gasifier
c. Lit the wood shavings with the gas range lighter. After 20 seconds, turn ON the fan to provide the air needed for proper combustion of fuel. After1 minute carefully close the gasifier. Quickly place the stirrerfollowed by the thermocouple.
d. Monitor the temperature inside the reactor chamber. Take note that the temperature should be above 260˚C to assume the presence of syngas.
e. When the temperature has reached 260˚C, a thick white smoke can be observed which is an indication of syngas.
f. To further check the syngas, lit the thick white smoke with the gas range lighter. A flame in the flare tower signifies the presence of the syngas.
g. Measure the temperature of the syngas using the Extech 42510 wide range Mini IR Thermometer. Monitor the temperature; take note of the maximum temperature that the gasifier can reach. When a decrease in temperature was observed, wait until it reaches 260˚C before checking again for the syngas.
h. When there is no more syngas observed, turn off the blower and allow the prototype to stand for

cooling for at least 30 minutes.

i. Discharge the char and dispose

RECOMMENDATION

Increase the inner diameter of the chamber to further increase the amount of feed in order to have higher syngas yield.

Add an air flow meter to monitor the supplied air coming from the blower. Excess air affects the quality of the syngas produced.

To have a complete analysis of the synthesis gas, search for an analyzer or a laboratory that is capable of detecting the total composition of syngas.

The higher the temperature, the higher the percent conversion of woodchips to syngas. To avoid heat losses, use ceramic fiber blanket to cover the reactor chamber. This can be used even without cement as an insulator.

Create a pyrex glass window on the reaction chamber. To address the tar and condensate formation, create a collector to be placed in between the pipes connecting the chamber and the flare tower.

For the ease and convenience of monitoring the temperature, it is more efficient to use infrared thermometer or pyrometer directed to the pyrex glass window.

Look for other types of filter that can purify the gas to get rid of the soots and tar.

Install an auto igniter in flare tower.

For further study, the researchers may use other types of wood in producing synthesis gas.

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