

# Analysis of the Synthetic Gas Production from Saw Dust Gasification

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## Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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## ABSTRACT

**Aims:** Produce combustible gas from sawdust for domestic house use.

**Study Design:** A fluidized bed gasifier suitable for sawdust gasification was used.

**Place and Duration of Study:** The study was done at the federal university of technology akure, Ondo state Nigeria

**Methodology:** Sawdust was first processed by converting it to pellets. Tests were carried out on the pellets using a bomb calorimeter using the ASTM-E771 standard. On experimental, the pellets were loaded into the reactor and then fired. Air was forced into the plenum, after which the air distributor plate evenly distributed jets of air in the bed resulting in complete and incomplete combustion.

**Results:** Experimental tests showed that the pellets have a heating value of 16.36 MJ of energy per kg and a higher percentage of volatile matter of 57.62% (ASTM-E872) and a lower percentage of fixed carbon than the initial sawdust sample. The produced synthesis gas composed of methane 63.4%, Ammonia 1.09%, Carbon monoxide 0.63%, Hydrogen sulphide 0.84% and carbon dioxide 34.04%.

**Conclusion:** The gas was ignited showing it was combustible.

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## 1. INTRODUCTION

Low energy fuels include wood and coal, while biomass wastes exists as: sawdust, wood chips, forest and forest products, and municipal waste. Some of these wastes such as sawdust abounds in vast quantities around the country and can be converted into energy. The world's current energy needs and its dependence on non-renewable sources presents an unsecure and unsustainable system of demand and supply. This results in unpredictable and volatile energy costs with far reaching effects. This was proven by the recent fluctuations in crude oil price between year 2014 and early 2015. Renewable sources of energy such as biomass can be "strategically useful" in alleviating similar problems [1].

Gasification represents one of the biomass energy conversion routes. According to the National Non-Food Crops Centre (NNFCC), gasification is a chemical process whereby solid material containing carbon such as coal or biomass is decomposed into gases through the use of heat [2].

Biomass gasification carries so much potential that it has been estimated to provide nearly a quarter of the total energy for the European Union in the next few years [3]. This is significant because it implies that at least the same is possible in countries and regions with the large quantity of the agricultural and agro-process wastes available in this part of the world. All these sources of biomass can be readily converted to energy products using relatively simple gasification systems.

Gasification is more efficient than direct combustion because the produced synthesis gas can be burnt at higher temperatures, converted in several synthesis fuels for vehicle and used to produce methanol and hydrogen [4]. The sources of the world energy supply are majorly from the non-renewables, and the present rates of their exploitation make them unsustainable. It is therefore imperative that we find more efficient energy pathways for extracting energy from various available sources. The rate of depletion of current fuel sources has increased with increasing global population with over 35% being used in homes alone (Fig. 1).

In developing countries such as Nigeria, 40 to 60% of energy is used in industry for heating and

powering mechanical drives [3]. Similarly, industries in the third world countries can be classified into three main groups:

- i. Household or cottage industries,
- ii. Small workshops and factories,
- iii. Large scale industries.

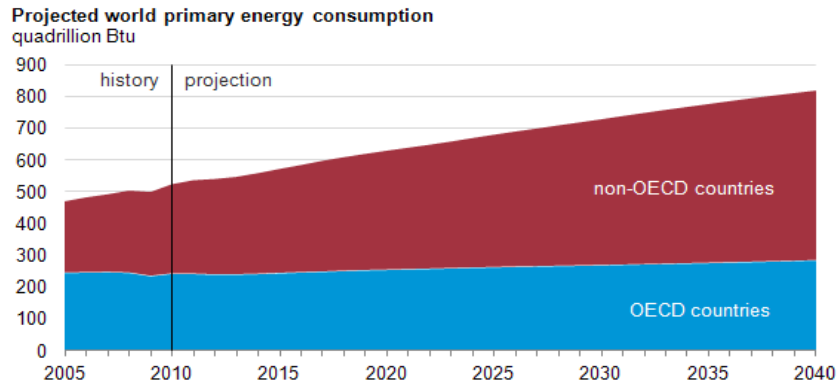
Household and cottage industries account for 50-75% of employment. Small and medium sized enterprises have recently been receiving attention globally especially in developing countries with the potential for the growth and development of the economy. This has resulted in significantly more small and medium sized enterprises leading to a consequential increase in their power and energy needs. It is therefore imperative to provide more alternative forms of energy for cottage and household industry use.

Another challenge that the rising global populations result to is in the generation of more wastes. These wastes are in different forms and of materials that will impact the environment negatively. Nigeria alone produces 0.66kg/capital/day of municipal waste [5], and has over 1.8 metric tons of sawdust that is usually set ablaze as a means of disposing it [6]. It is estimated that Nigeria produces over 3.89 million cubic meters of sawdust per year [7]. Sawdust easily becomes an environmental hazard because it is a source of leachates affecting aquatic habitats, surface and ground water. Leachates is formed when land waste such as sawdust decay and rain fall which rinse the chemical form to ground water causing pollution [8]. It is relevant to note that the problem of waste can be capitalized upon to provide a solution to the rising energy needs. This is a valuable source of biomass that this project seeks to explore being cheap, available, free, renewable, sustainable and abundant in the tropical region of Nigeria.

## 2. MATERIALS AND METHOD

### 2.1 Sawdust Pellet Preparation

The challenge with sawdust gasification is its high opposition to inter-particulate air flow. This is overcome by pelletizing the sawdust. Pelletizing the biomass is the form of densification employed. This involves the application of a binder, compression and then extrusion through a die to a size of 14mm



**Fig. 1. Projected world energy consumption**

(Source: U.S. Energy Information Administration, *International Energy Outlook 2013*) [9]

diameter and an average length of 75mm. This is followed by drying the densified biomass. Sawdust was collected at a local sawmill, and sieved to remove large particles. Minimum pellet sizes of 6mm are the standard with a maximum size of 14mm. It is also understood that a uniformly sized feed stock are more successful in gasification processes [10]. The pelletizer is loaded with sawdust prepared by mixing six parts of sawdust with one part of starch (parts by volume). It was realized that when little or no binder is used, it resulted in temperatures in the range of  $70 \pm 5^\circ\text{C}$  as measure using an infra-red temperature gun. This is indicative of very high resistive forces are produced in the pelletizer. This suggests that the binder also serves as a lubricant for the biomass during pelletization. Furthermore, the produced pellets are quick to get bone dry within 8 hrs of being sun dried only. This is a shorter duration than that of briquettes which takes about 24 hrs

and above [11]. This is because it has a smaller diameter and is more compact. Additionally, the tapered die forces excess water out during the pelletizing process. The pelletizer has a throughput rate of 12.5 mm/sec and shown during production in Plate 1. Samples of the pellets are produced having a diameter of 14mm and average length of 75 mm (Plate 2).

## 2.2 Analysis of Feedstock Composition

After pelletizing it is important to carry out tests on it for purposes of evaluating the performance of the gasifier. The following tests were carried out. For reasons of comparison, tests were also carried out on the raw sawdust. The two samples were identified and were given labels A and B (Sawdust and pellets respectively). Some of the equipment and apparatus employed are shown in Plates 1 and 2.



**Plate 1. Pellets in production**



**Plate 2. Produced pellets**

### 2.2.1 Moisture content détermination (ASTM-E871)

The instruments used to carry out the analysis in order to determine the Moisture Content of Pellets and Sawdust are: Crucible, Spatula, Beam balance, Muffle Furnace (Plate 3), Desiccator (Plate 4), mortar, pestle and stop watch.

The weight of the Crucible was determined with the aid of a digital beam balance, noted and recorded as  $w_1$ .

The pellets are ground in the mortar to a fine powder.

The determination of moisture content is carried out by adding 1.00g of the powdered sample to the crucible and the weight noted and recorded as  $w_2$ .

The Crucible containing the sample was heated in a muffle furnace at  $103 \pm 2^\circ\text{C}$  for one hour and thereafter taken out, the sample was cooled in a desiccator and weighed again until the weight became constant ( $w_3$ ). The loss in weight represents moisture content.

The percentage moisture content was then calculated, using the equation 1

$$\% \text{ MC} = \frac{w_2 - w_3}{w_2 - w_1} \times 100\% \quad (1)$$

Where:

$w_1$  is the weight of the Crucible in grams.

$w_2$  is the weight of the Crucible with the sample in grams.

$w_3$  is the weight of the Crucible with the sample after being cooled in the desiccator in grams.

% MC is the percentage moisture content.

### 2.2.2 Volatile matter determination (ASTM-E872)

The instruments used to carry out the analysis in order to determine the Volatile Matter of the samples are: Crucible, Spatula, Beam balance, Muffle Furnace, Desiccator and stop watch. To determine the Volatile Matter, the samples were identified and were given sample labels. The weight of the crucible was determined with the aid of a digital beam balance, noted and recorded as  $w_4$ . 1.00g (weight) of the sample was added to the crucible and the weight noted and recorded as  $w_5$ .

The crucible containing the sample is covered and was heated in a muffle furnace at  $950^\circ\text{C}$  for 7 minutes and was thereafter taken out, cooled in a desiccator and weighed as  $w_6$ . The percentage volatile matter was then calculated, using the relation in equation 2

$$\% \text{ VM} = \frac{w_6 - w_4}{w_5 - w_4} \times 100\% \quad (2)$$

Where:

$w_4$  is the weight of the crucible in grams.

$w_5$  is the weight of the crucible with sample in grams.

$w_6$  is the weight of the crucible with sample after being heated in the muffle furnace at the temperature of  $950^\circ\text{C}$  and cooled in the desiccator.



Plate 3. Muffle furnace



Plate 4. Desiccator

### 2.2.3 Ash content determination (ASTM-D1102)

The instruments used to carry out the analysis in order to determine the Ash Content of the samples include: Crucible, Spatula, Digital Beam balance, Muffle Furnace, Desiccator and stop watch.

To determine the Ash Content, the samples were identified and labeled. The weight of the crucible was determined with the aid of beam balance, noted and recorded as  $w_4$ . 1.00g (weight) of the sample whose Ash Content was to be determined was added to the crucible and weighed, noted and recorded as  $w_7$ . The crucible containing the sample was left open and was burnt (in the presence of air) in a muffle furnace at 750°C till a constant weight was obtained. It was thereafter taken out, cooled in a desiccator and weighed with the aid of beam balance and the weight was recorded as  $w_8$ .

The percentage Ash Content was then calculated, using the relation in equation 3.

$$\% \text{ASH} = \frac{w_8 - w_4}{w_7 - w_4} \times 100\% \quad (3)$$

Where:

$w_4$  is the weight of the crucible in grams.

$w_7$  is the weight of the crucible with sample in grams.

$w_8$  is the weight of the crucible with sample after being burnt in the muffle furnace at the temperature of 950°C and placed in the desiccator.

### 2.2.4 Fixed carbon determination

The percentage of Fixed Carbon is determined by subtracting the percentage moisture content, volatile matter and ash from 100. the relation is shown in equation 4.

$$\% \text{ Fixed Carbon} = 100\% - (\% \text{moisture content} + \% \text{Volatile matter} + \% \text{Ash}) \quad (4)$$

### 2.2.5 Nitrogen content (ASTM-E778)

The Nitrogen content contained in the samples was determined by using Kjeldahl's Method.

The crucible was weighed in a digital beam balance and its weight tarred to zero. 1 g of the sample to be determined was added to the

crucible. The crucible containing the sample was heated with concentrated sulphuric acid in the presence of potassium sulphate and copper sulphate in a long necked flask called Kjeldahl's flask thereby converting the nitrogen in the sample to form a clear solution of ammonium sulphate. This solution was then treated with 50% Sodium Hydroxide solution which converted the ammonium sulphate to ammonia. This ammonia is distilled over and absorbed in sulphuric acid. The volume of unused sulphuric acid is then determined by titrating (Plate 5) against a standard Sodium Hydroxide solution. This reveals the amount of acid neutralized by the ammonia liberated from the sample. Subsequently the percentage nitrogen is determined using the relation in equation 5.

$$\% \text{ Nitrogen} = \frac{\text{Volume of acid used} \times \text{Normality}}{\text{Weight of Sample}} \times 1.4 \quad (5)$$

The volume of acid used =  $V_1 - V_2$

Where,

$V_1$  = Volume of sulphuric acid neutralized in blank

$V_2$  = Volume of sulphuric acid neutralized in determination

### 2.2.6 Energy content determination

The equipment and materials used to determine the Energy Content of the samples include: Bomb Calorimeter (CAL e2K see Plate 6) which consists of Filling station (CAL K-3) and Vessel/Bomb (CAL 2K-4), crucible, full oxygen cylinder, desiccator, silica gel, beam balance, soft cloth, Spatula, PC keyboard, cotton thread, firing wire, crucible holder, lid assembly and Benzoic acid standard. The crucible used was washed with clean water and dried in a desiccator containing silica gel as the drying agent. The crucible was weighed in a digital beam balance and the weight was tarred to zero.

The sample was well mixed and 0.50g of it was weighed into the dry crucible with the aid of beam balance, the sample identification and mass was entered via the keyboard at the onset.

The pre-cut length of firing cotton was inserted by looping it over the firing wire and the weighed crucible and sample was inserted into the crucible holder, it was ensured that the firing cotton touched the sample.

The lid assembly was inserted into the vessel body and the cap of the vessel was screwed



**Plate 5. Titrating apparatus**



**Plate 6. Bomb calorimeter**

down until it touched the top of the lid. The vessel was placed into the vessel holder under the filling station and was kept upright and filled with oxygen to a pressure of 3000 kPa.

### 3. RESULTS AND DISCUSSION

#### 3.1 Feedstock Assessment

The fuel to be utilized is sawdust. Table 1 presents the results of proximate and ultimate analysis of the sawdust and pellets which lies in the range of that obtained by Li et al. (2013).

Comparing the laboratory results of the dried sawdust and the pelletized form yields the result shown in Table 1.

#### 3.2 Gas Collection and Analysis

The pelletized saw dust was fired in a gasification reactor to produce combustible gas. The synthesis gas was collected for analysis. Gas canisters were used to collect three samples of the produced gas at reactor temperatures of 600°C, 650°C and 700°C (Plate 8). They were first vacuumed and sealed. Subsequently, the canisters were placed in an ice bath to drop temperatures and ease the flow of gas into them. The Gas Chromatograph used is shown in Plate 9 and the system conditions are depicted in Table 2.

**Table 1. Proximate analysis and energy content of sawdust and pellets**

S/N	Percentage composition (%)	Standard used	Dried sawdust	Dried pellets
1.	Moisture Content (wt %)	ASTM-E871	15.20	18.46
2.	Fixed Carbon (wt %)	(1-MC-AC-VM)	16.15	21.13
3.	Ash (wt %)	ASTM-D1102	3.09	2.79
4.	Volatile Matter (wt %)	ASTM-E872	65.56	57.62
5.	Energy (MJ/Kg)	ASTM-E711	18.072	16.364

**Table 2. System conditions for the test**

Component	Condition
GC	HP 6890 Powered with HP ChemStation Rev. A 09.01 [1206] Software
Carrier Gas	Helium at 20ml/min
Inlet Temperature	145°C
Inlet Flow	Helium at 26 ml/min
Column Type	Haysep DB 100/120; Altech, Deerfield, Illinois
Column Dimension	30 x 1/8mm x 0.85µm
Oven Program	Temperature at 140C, 6min. Ramped at 50C/min to 175C and held
Detector	TCD
Detector Temperature	200C
Detector Reference Flow	40 ml/min





**Plate 7. The Ignited synthesis gas      Plate 8. Gas canister**



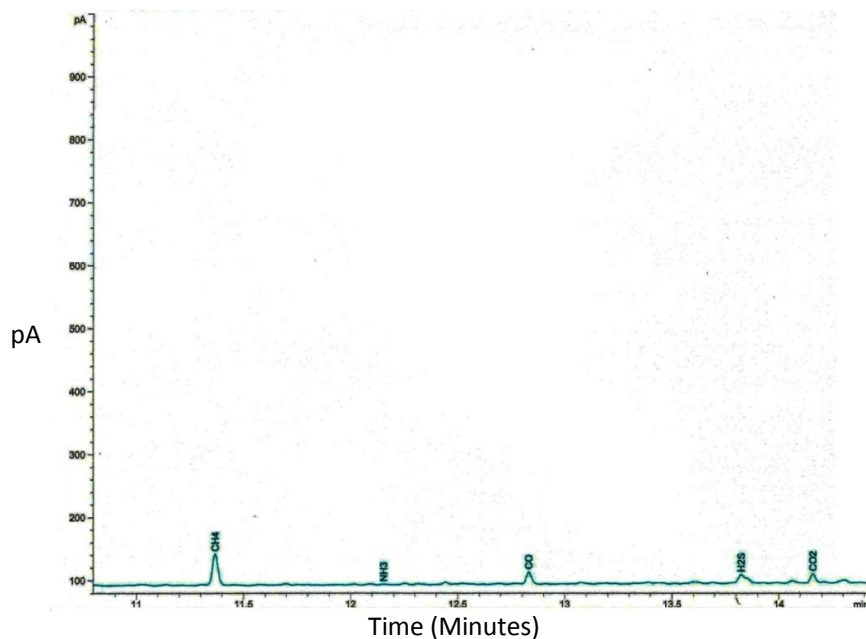
**Plate 9. The gas chromatography system used**

The carrier gas employed is helium and a thermal conductivity detector (TCD), also known as a Katharometer is used. Chromatograms plotting the percentage abundance of the gas

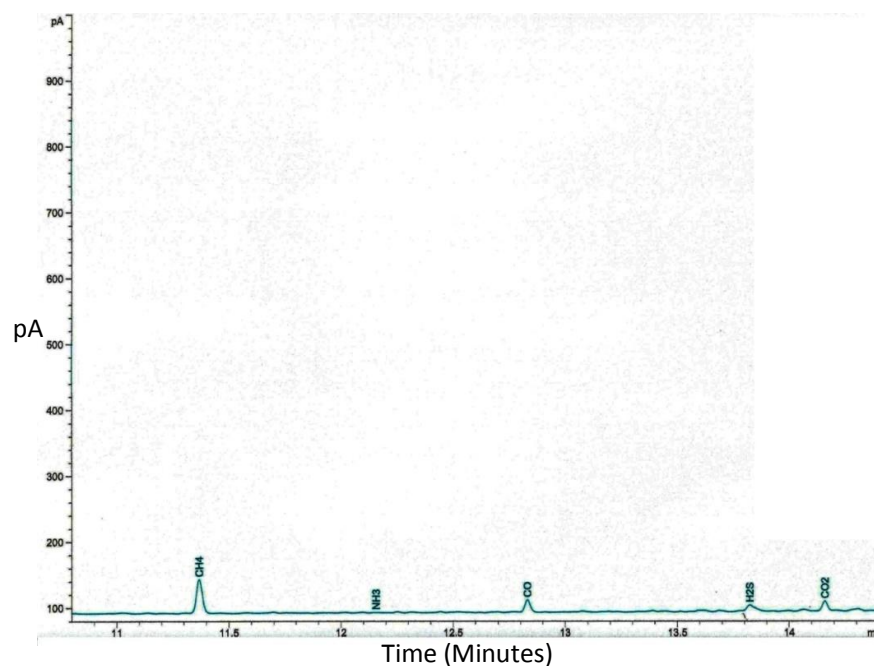
against the gas components are shown in Figs. 2 to 4, and this was followed with the normalized percentage report in Tables 2 to 5.

**Table 3. Normalized percent report of gas at 600°C**

<b>Sorted by Multiplier Dilution</b>				<b>Retention Time 1.0000 1.0000</b>			
<b>Ret Time (min)</b>	<b>Signal</b>	<b>Type</b>	<b>Area</b>	<b>Amt/Area</b>	<b>Norm%</b>	<b>Grp</b>	<b>Name</b>
11.370	1	VV	97.62069	1.19354 e-1	63.647859	1	CH <sub>4</sub>
12.157	1	VV	4.25534	5.07239 e-2	1.179098	1	NH <sub>3</sub>
12.833	1	VV	39.31828	4.13445 e-3	0.888006	1	CO
13.620	1	VV	20.75962	7.46918 e-3	0.847024	1	H <sub>2</sub> S
14.307	1	VV	23.67754	2.58524 e-1	33.438013	1	CO <sub>2</sub>
<b>Results Total</b>			<b>185.63147</b>		<b>100</b>		



**Fig. 2. Constituent gas percentage abundance at 600°C**



**Fig. 3. Constituent gas percentage abundance at 650°C**

The system is calibrated to show the abundance of methane between 11 and 12 minutes, and carbon monoxide at the 12.5 to 13 minute interval. These are the expected gases as shown in the work of [12]. They are a product of the char gasification process and a result of the Boudouard Reaction and Hydrogen gasification reaction.

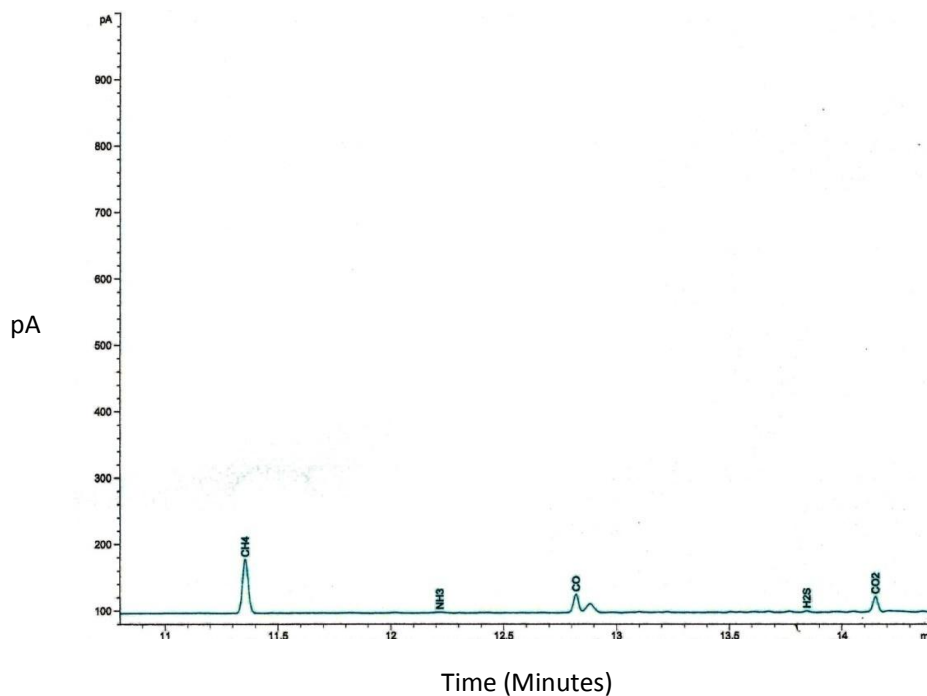
The results from the gas chromatography are shown in Figs. 2, 3 and 4, these are followed by the Normalized Percent Reports at 600°C, 650°C and 700°C depicted in Tables 3 to 5. The average percentage contents across the three samples of the produced synthesis gas are; Methane ( $CH_4$ ); 63.40%, Ammonia ( $NH_3$ ): 1.09%, Carbon Monoxide ( $CO$ ): 0.64%, Hydrogen



Sulphide ( $H_2S$ ):0.84% and Carbon Dioxide ( $CO_2$ ): 34.02%. Most of these gases are present in a usual gasification process. The percentage report show the retention time of methane as 11.3 minutes, ammonia as 12.2 minutes, carbon monoxide as 12.8 minutes,

**Table 4. Normalized percent report of gas at 650°C**

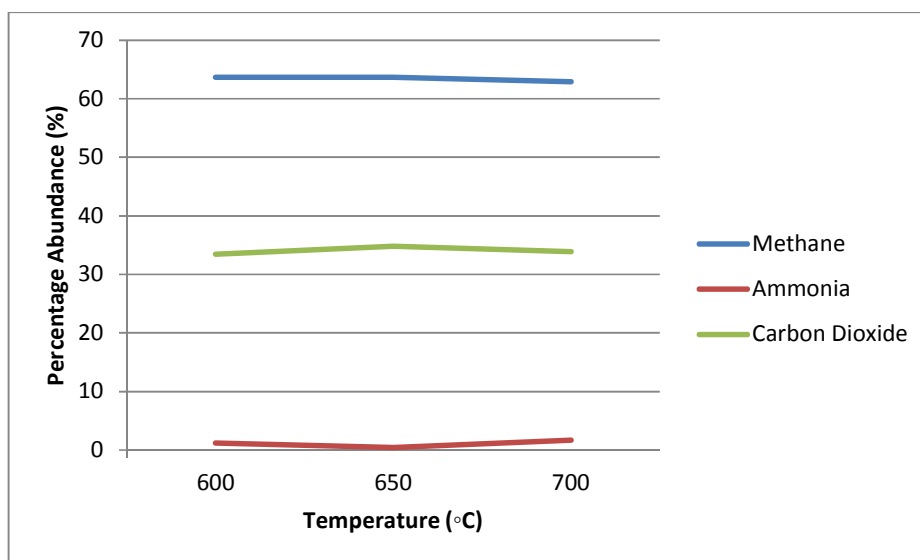
Sorted by				Retention Time			
Multiplier				1.0000			
Dilution				1.0000			
Ret Time (min)	Signal	Type	Area	Amt/Area	Norm%	Grp	Name
11.370	1	VV T		1.51571 e-1	63.659239	1	CH <sub>4</sub>
12.156	1	VV T		2.32755e-2	0.430582	1	NH <sub>3</sub>
12.833	1	VV T		2.33889e-3	0.431644	1	CO
13.619	1	VV T		6.60350e-3	0.713700	1	H <sub>2</sub> S
14.308	1	VV T		2.55555e-1	34.764835	1	CO <sub>2</sub>
<b>Results Total</b>					<b>100</b>		



**Fig. 4. Constituent gas percentage abundance at 700°C**

**Table 5. Normalized percent report of gas at 700°C**

Sorted by				Retention Time			
Multiplier				1.0000			
Dilution				1.0000			
Ret Time (min)	Signal	Type	Area	Amt/Area	Norm%	Grp	Name
11.357	1	VV	157.79660	6.37107 e-2	62.896113	1	CH <sub>4</sub>
12.217	1	VV	19.68459	1.36481 e-2	1.680783	1	NH <sub>3</sub>
12.822	1	VV	56.49559	1.66020 e-3	0.586799	1	CO
13.546	1	VV	7.17543	2.15932 e-2	0.969346	1	H <sub>2</sub> S
14.359	1	VV	16.44097	3.29257 e-1	33.866960	1	CO <sub>2</sub>
<b>Results Total</b>					<b>100</b>		



**Fig. 5. Normalized percentage against temperature**

hydrogen sulphide as 13.5 minutes and carbon dioxide as 14.4 minutes. There was a consistently higher percentage of methane in all three samples, an average of 63.4% in all samples. For comparison and perspective the normalized percentage is plotted against temperature in Fig. 5.

Looking at this chart it is easy to see that a high percentage of the gas is methane and this changes slightly over this temperature range suggesting that a larger temperature difference is required to make significant difference. [13] showed that this is expected from a usual gasification process but can be altered by the excess air/fuel ratio which was given by [14] as 0.3. The excess air/fuel ratio directly affects the reactions within the reactor and determines the percentage compositions of the syngas. Increase in the air flow rate would result in a complete combustion and consequently a rapid deterioration of the gasification due to complete oxidation of gaseous products.

#### 4. CONCLUSION

The produced synthesis gas was also taken for lab analysis using a gas chromatography mass spectrometer system to determine its constituent gases. A major component was methane which is a valuable combustible gas produced from sawdust which exists in large amounts around the country. A thermal conductivity detector (TCD) was used for the analysis which has a broad range of gases that can be detected.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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