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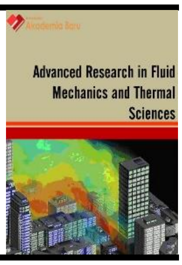

Study of Combustion Performance of Syngas from Biomass Waste (Wood Waste) in a Gas Burner

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ABSTRACT

Biomass or bio-waste has a potential to be promoted as a viable energy sources. In this study, the characteristics and the combustion performance of syngas produced from biomass waste especially wood waste gasification were investigated in term of gas composition and emission released in a downdraft and fluidized bed gasifiers. The flame length, gas characteristic and formation were determined beside energy level produced from both gasifier systems. Syngas generated from wood waste were combusted in a gas burner at temperature 762°C and 505°C for the cases of downdraft and fluidized bed respectively. As results from combustion, NO_X, SO_2 and CO produced 56ppm, 1ppm and 33ppm respectively. Meanwhile, the gas compositions from the combustion were about 0.04%, 1.4%, 0.5%, 97.9% and 0.1% for H_2, N_2, CH_4, CO, and CO_2 respectively. In this study the flame length of the combusted wood wastes in a downdraft showed unstable flame (oval shape) with the longest flame of 12.5 cm if compared to fluidized bed at 5.4 cm which was more stable in a rectangular shape.

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1. Introduction

Malaysia has a drastic growth in population and high energy demand. Having dependent mainly on oil and gas for half a century, Malaysia has started to realize the importance to adopt renewable energy. The government initiative to encourage researchers to study and develop on any potential material that could contribute for energy supplied and secured for future generation used [1]. Mekhilef *et al.,* [2] discussed that fossil fuels as a natural resources energy will not sustain any more soon because of environmental impacts and depletion of the reserves. Asadullah [3] shared that there are many ways of generating electricity using the heat which produced in combustion, including the steam turbine, the reciprocating steam engine, Stirling engines, indirect fired gas turbines and direct fired gas turbines. Ahmad *et al.,* [4] stated that Malaysian Government has taken continuous effort to encourage researchers to focus on the development of Renewable Energy through own

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initiative to promote programs such as Malaysian Industrial Energy Efficiency Improvement Project (MIEEIP), Small Renewable Energy Power Program (SREPP), Building Energy Efficiency Program (BEEP), Green Building Index (GBI) and Malaysia Building Integrated Photovoltaic Technology Application (MBIPV), and Biomass Grid-Connected Power Generation and Co-Generation (Biogen). These efforts have provided good platform for the growth of renewable energies.

Mekhilef *et al.,* [2] stated that since late 1990, the concept of waste to wealth had been promoted and became popular. The concept is based on unwanted wastes which are converted into valuable energy while reducing waste generated and increase the economy efficiency mainly where it was widely used for power generation [5]. Molino *et al.,* [6] declared that biomass gasification is an efficient and advanced technology for extracting the energy from biomass and has received increasing attention in the energy market. This system normally converts wood residues into gaseous fuel suitable as boiler fuel. Ong *et al.,* [7] admitted that the crucial challenge faced by power sector in Malaysia currently is the issue of sustainability. Therefore, motivated researchers explore the alternative energy like biomass, solar, wind and mini hydro energy to ensure reliability and security of energy supply in this country. Nicoletti *et al.,* [8] reported that another major issue arise from fossil fuel burning is environmental pollution. The excessive emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are detrimental to the environmental and human health.

In Malaysia, there is a big potential for biomass or bio-waste to be used and as a subject matter study on renewable energy. It can be done with knowledge and proper management by converting the waste into valuable energy. Recently, there has been great progress in the development of gasification technology. Many kinds of biomass gasification processes have been developed treating different materials for various purposes. Rupesh *et al.,* [9] discussed that the gasification is known as thermochemical process by which low energy density fuels like biomass will be converted into gaseous fuels with the aid of a series of chemical reactions. Malek *et al.,* [10] reported that Malaysia uses locally available wood and biomass fuels as alternatives. Most researchers know that wood and woody materials tend to be low in ash content while the agricultural materials can have high ash contents. Biomass fuels properties often have high moisture content, which could result in relatively low net calorific value. However, not all biomass gasification technologies are able to produce the clean gas. Nicoletti *et al.,* [8] reported the excessive emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are detrimental to the environment and human health. These issues drive many researchers to study and develop the beneficial renewable energy technologies for controlling any harmful emissions released to the environment. This study will focus on syngas production through selected gasification technique (Downdraft and Fluidized Bed) using wood waste as feed stock or raw material. The syngas produced from the gasifier system will be sending for characterization to determine and compare the syngas performance generated from the system.

2. Methodology

2.1 Gas Characteristic

The test measurement for the solid (Raw material / Feed stock) and gas composition will be send to special laboratory. This is to determine the performance level of the gas generated during gasification. Most researchers compared the result with previous assessment as a reference to produce the quality of syngas generated from the selected gasifiers. Most of the common measurement test done by researchers included proximate analysis, ultimate analysis, calorific value and gas composition.

Proximate Analysis is test to measure the content of moisture, volatile matter and ash of the solid sample. The fixed carbon content is calculated by subtracting the sum of moisture, volatile matter, and ash contents. Özyuguran *et al.,* [11] discussed on their finding, besides calorific value, the moisture content is another important criteria since it affects the combustion performance as well as the physical performance of a densified product. An increase in moisture content will cause a drop in calorific value and slow down the ignition speed of palm biomass pellet or briquette. According to Mondal *et al.,* [12] high volatility matters present the advantage of requiring lower temperature for decomposition and reaction process. Cai *et al.,* [13] discussed that the high volatile matter content in wood waste indicates high reactivity and is suitable for thermochemical energy conversion process such as pyrolysis and gasification for syngas production. To perform the tests, the proximate analysis of biomass only require a simple oven for determination of moisture content and a furnace for determination of volatile matter and ash contents which can be easily found in an common laboratory.

Meanwhile, ultimate analysis is conducted in order to determine the elemental content in percentage by mass. Information such as the exact amount of C, H, N and S in biomass content is useful for environmental impact study and to determine the chemical compositions of biomass as well as to predict what is the final gas composition and emission. Ultimate analysis test will look into chemical composition in a solid material in term of amount of carbon C, Hydrogen H, Nitrogen N and Sulfur S. These informations are essential for the development of syngas because it may help researchers to predict and analyze the combustion phenomena where the material properties and composition greatly affect combustion performance. However, ultimate analysis and determination of the macromolecular ingredients of biomass such as lignin, cellulose, and hemicellulose require sophisticated equipment with good calibration and very sensitive analytical experiments. Gas chromatography is the best machine to measure the chemical composition of a gas.

The most important aspect in determining the quality of fuel is calorific value (CV) measurement. The main concern relevant to use of biomass energy resources is that the energy density of biomass is typically lower than that of fossil fuels such as coals. The calorific value of biomass is closely affected from moisture content that it may reach very high levels especially in case of green biomass and waste materials. Özyuguran *et al.,* [11] shared their finding where the fixed carbon content of biomass can be easily connected with the calorific value since it has a positive effect on the energy potential of biomass. High volatile matter content does not guarantee high calorific value since some of the ingredients of volatile matter are formed from non-combustible gases such as CO_2 and H_2O. Ash has not only an inert effect on the calorific value of a fuel but also it shows some detrimental effects on the apparent heat obtained from burning of biomass. The energy need of ash forming inorganics for thermal breakdown and phase transition is taken from the burning energy of biomass and it leads to reduction in the calorific value. There still exists extra unknown factors that influence the higher heating value (HHV) of biomass and such factors add more difficulty in modeling of this property. Bilandzija *et al.,* [14] in their studies found that the heating value of a fuel can be reported in terms of a 'lower' (LHV) or 'higher' (HHV) value which the value is the same with Calorific value for Solid (HHV) and Calorific value for Gas (LHV). This is motivating the researchers to develop various mathematical models to predict the calorific value of biomass.

The inherent variability in composition and heating value in synthesis gases cause significant challenges towards their usage in practical combustion system. The gas composition was observed to be influenced by the feed stock composition, water content, reaction temperature and pyrolysis process resulted from combustion in the gasifier system. The gas composition consists of H_2, CO, CH_4 and other hydrocarbons are known as combustible compounds while CO_2 and N_2 are non-combustible compounds in producer gas. This is the typical gas that is always referred by researchers from previous study. Samiran *et al.,* [15] discussed that H_2 and CO typically contribute 50% of the energy in the product gas, while the remaining energy is contained in CH_4 and (aromatic) hydrocarbons. Total lower heating value (LHV) syngas varies significantly depending on the composition gas. Higher contents of the incombustible gases N_2 and CO_2 have an impact on the LHV reading. Factors such as feedstock, gasification method and temperature are also impacting the LHV.

Combustion tests were performed to determine the level of effectiveness of biomass (wood waste) generating high quality clean gas released to the environment. In this experiment, gaseous emissions such as NO_X, CO, CO_2 will be analyzed to determine the effect of these harmful gases. Habib *et al.,* [16] performed a numerical investigation on a 200 MW boiler in non-premixed mode for studying the emission characteristics of syngas. Result from the analysis shown that CO-rich syngas (67% CO: 33% H2) emitted the highest NO_X due to the high flame temperature. While, these result differ from the findings of Liu and Shih from their studies [17] where NO_X emission level was shown to decrease with increasing CO fraction in syngas in a numerical study involving a micro gas turbine under non-premixed mode.

2.2 Flame Profile

In this study the flame profile was determined by the flame length which is influenced by the temperature profile, feedstocks, gasifier system, parameter measurement and burning rate in a combustion test. The use of swirled as a flame holder helps to stabilize the flame in front of burner outlet. During the combustion process, temperature along the combustion chamber was monitored. There are eight points, attached with K-type thermocouples, along the combustion chamber which is connected to a midi data logger to measure the wall temperature. The syngas generated from the reactor will be transferred to the combustion chamber. The measurement of the flame length was performed using standard ruler (cm) in combination with high speed camera for capturing of the flame images during a combustion performance test. The flame length produced from both gasifier systems will be compared and discussed.

3. Experimental Setup

This part presents the operating procedure for the gasifiers and also the gas characteristics determination. This section also described the experimental rig set-up for the combustion tests of the wood waste.

3.1 Feedstock

Downdraft Gasifier, the wood waste feedstock come with the standard size and do not require any extra machining process for size reduction. The experiment begins with the drying process under the open sun with temperature within 32 to 36°C which is to ensure the material supplied is with minimal moisture content before using it during combustion tests as shown in Figure 1(a). However for fluidized bed gasifier, the wood waste size need to be reduced to size <3mm. The sample preparation for wood waste for fluidized bed (FB) requires it to be grinded. The sample was then dried under the sun with temperature within 32 to 36°C to ensure the material having low moisture content as in Figure 1(b).

(a) (b)

Fig. 1. (a)Downdraft Feedstock; (b) Fluidized Bed Feedstock

3.2 Downdraft Setup

A 3 kg of wood waste will be fed to the reactor chamber through the top. Then the cover will be tightly closed before the combustion starts until the temperature in the reactor reached a certain level. Usually, syngas starts to generate at a certain temperature, around 700°C and above depending on the feedstock. The syngas was then channeled to the cyclone separator for separating particles and as. For cooling purposes the syngas was then send to the heat exchanger before being supplied to the combustion rig or any other purpose (Figure 2).

Fig. 2. Downdraft Gasifier

3.3 Fluidized Bed Setup

Grinded wood waste will be fed into the hooper before entering the reactor chamber through a screw feeder. It will be manually combusted until it reaches a certain temperature before the system starts producing syngas. Figure 3(a) shows the fluidized bed gasifier system while the control panel shown in Figure 3(b) is used by the operators to fine-tune the system. The temperature in this experiment will be monitored. For the fluidized bed gasifier, air is blown through a bed of solid particles alumina at sufficient velocity to maintain the particles in a state of suspension. The alumina bed is externally heated to provide sufficient energy for the endothermic reforming reaction process during operation.

(a) (b)

Fig. 3. (a) Fluidized Bed; (b) Machine Panel Setting

3.4 Combustion Chamber

The combustion chamber shown in Figure 4(a) is made from high cast cement insulating an open ended rolled up mild steel plates concentrically. At the combustion chamber area, smoke will be presence at the tip of the swirler as shown in Figure 4(b). The flame was ignited manually and controlled by air blower to produce laminar flow as shown in Figure 4(c). Gas smoke can be monitored by looking at the flare at the opened valve. The color will change from white to grey and at this moment temperature will be recorded. Operators can ignite the flair immediately, once the dark gray smoke color is clearly seen.

(a) (b) (c)

Fig. 4. (a) Combustion chamber; (b) Smoke at burner; (c) Ignition the flame

4. Results and Discussion

This part presents the results and findings of the study. The properties of the wood waste will be summarized and compared with the fuel standard. The performance of the fuels is described based on its physical solid performance in term of calorific value, proximate analysis, ultimate analysis and gas performance as well as calorific value of the gas, composition, flame length, wall temperature profile and emissions generated.

4.1 Properties of the Feedstock

The physical properties and chemical composition of the wood waste (solid) are required to determine the fuel properties of the syngas obtained. The common physical properties tests are calorific value, high heating value (HHV), proximate analysis and ultimate analysis. Table 1 shows the properties result of the wood waste.

Table 1
Properties of Wood Waste

Proximate analysis (wt% dry basis)	(%)	Ultimate analysis (wt% dry basis)	(%)	HHV (MJ/kg)
Moisture content	10.23	C	43.69	17.936
Volatile matter	79.16	H	6.33	
Fixed carbon	9.69	N	1.96	
Ash	0.92	S	0.05	

The CV/HHV is the key parameter to evaluate the fuel quality and measure the level of energy produced by solid wood waste material in energetic applications [18]. In term of moisture content, volatile matter, fixed carbon and ash content, the result have significant difference when compared to each other. The proximate result could be influenced by the moisture content, size, shape, density and chemical composition of the biomass. Overall, the result shows that wood waste has good potential to be explored as energy sources. Ultimate analysis shows that carbon, C of 43.68% is the highest content extracted from the wood waste. Second, hydrogen, H content of about 6.33% and others like nitrogen, N and sulfur, S are negligible.

4.2 Combustion Performance
4.2.1 Wall temperature

During combustion process, temperatures along the combustor wall were monitored. Figure 5 shows the wall temperature profile generated from syngas produced from downdraft and fluidized bed gasification.

The wall temperature readings are depending on the fuel's calorific values. Temperature profile for downdraft gasifier shows a normal trend. The temperature has risen starting at 100mm distance and increases rapidly till the distance of 500 mm. This is because the fuel and air are combusted homogeneously due to well-mixed mixture at the middle of the chamber generating high temperature. However, once passing the distance of 500mm, the wall temperature drops until reaching the end of the combustion chamber (800mm). However, for fluidized bed gasifier, different trend was observed where it is the reverse of the downdraft wall temperature trend. At the distance of 100mm and 200mm the temperatures recorded were 392.5°C and 380°C, and drop drastically at distance of 300mm until 800mm. This is because the energy produced from fluidized bed gasifier is weaker and resulted in flame length generated is shorter compared to downdraft system.

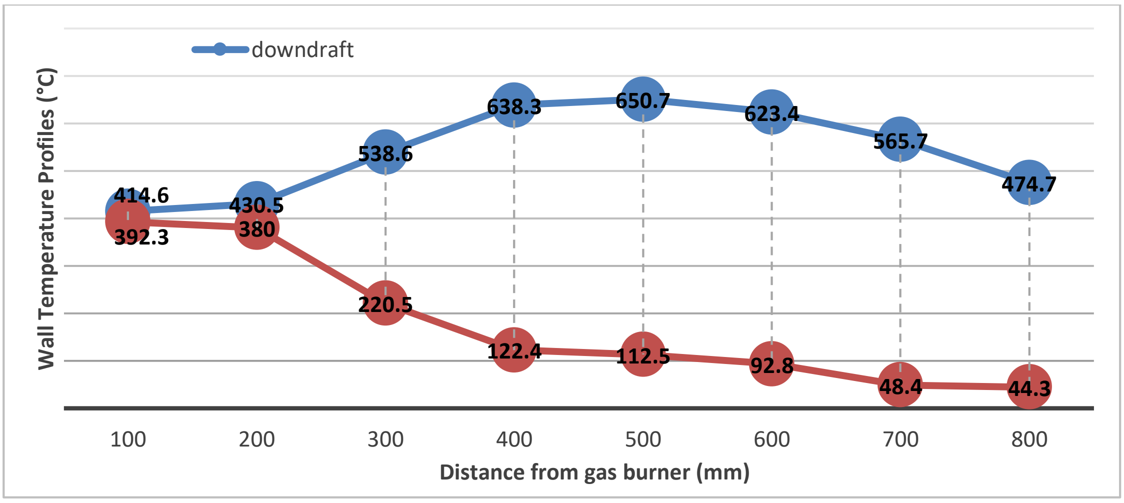

Fig. 5. Temperature profile for downdraft and fluidized bed in a combustion chamber

4.2.2 Flame profile

Flame length is influenced by the temperature profile, feedstock type and condition, gasifier system, parameter and burning rate in a combustion test. The use of swirler helps stabilization of flame fronts at the burner outlet. Study performed by Samiran *et al.,* [19], combusting the fuel/air mixture results in rich flame, where the post-flame region is more intense, sooty and characteristically yellowish-orange in color. The baseline cases for comparison are fuel-rich syngas and air-rich syngas. From this study, the measurement for flame length resulted from downdraft and fluidized bed are shown in Figure 6.

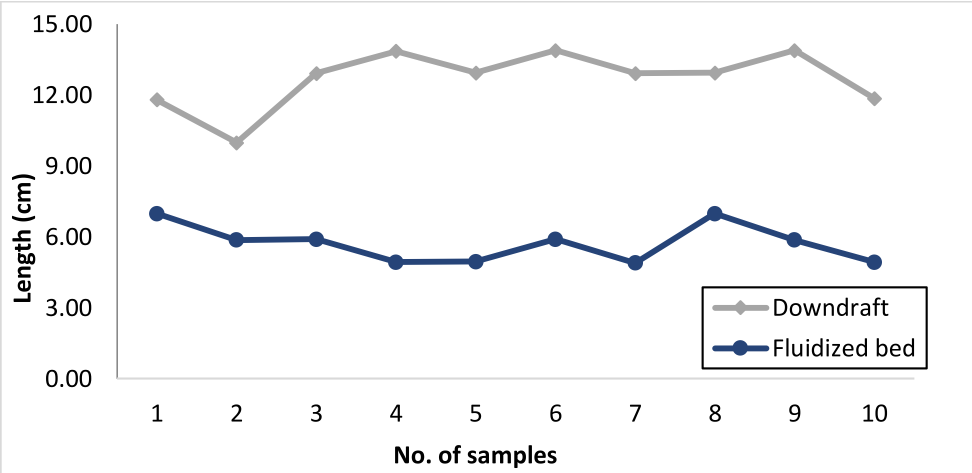

Fig. 6. Flame Length measurement for downdraft and fluidized bed gasifier

The result shows that the longest flame is produced from the downdraft gasifier which achieved an average of 12.8 cm and the fluidized bed with an average of 5.8 cm only. It means that the blowout limit produced from downdraft is more intense. This also indicates that the level of energy produced from both gasifier systems is different. Figure 7(a) and Figure 7(b) show the photographs taken during flame length measurement.

(a) (b)

Fig. 7. (a)Downdraft Flame; (b) Fluidized bed Flame

4.2.3 Gas composition

The gas composition was observed to have some influence from the feed stock composition, water content, reaction temperature and pyrolysis process. Table 2 shows the gas composition result from wood waste syngas where it have been collected through proper methodology with TAR sampling system and stored using the Tedlar bag before being sent to laboratory for tests.

Table 2
Gas Composition (Wood waste)

Biomass type	Dry gas composition (% vol.)					Lower heating value
	H_2	N	CH_4	CO	CO_2	LHV (MJ/kg)
Wood Waste	0.04	1.38	0.54	97.92	0.12	10.267

The H_2, CO, CH_4 and other hydrocarbons are combustible compounds while CO_2 and N_2 are non-combustible compounds in producer gas. From the result of Table 2, we can conclude that the type of syngas generate are in the Syn 3 type which was grouped under pure CO gas. It is noted that Syn 3 contains not only CO but also diluents of CO_2 and CH_4 as shared by Samiran *et al.,* [19]. The big different is observed in term of CO and N_2 content when comparing with other study are that the amount of CO is influenced by N_2 content in the syngas. Samiran *et al.,* [15] discussed that H_2 and CO typically contribute 50% of the energy in the product gas, while the remaining energy is contained in CH_4 and (aromatic) hydrocarbons. Total lower heating value (LHV) of the syngas varies significantly depending on the composition gas. Higher contents of the incombustible gases N_2 and CO_2 have an impact to the LHV reading.

4.2.4 Gas emission

The emission characteristics tests were performed in order to know the level of effectiveness of biomass (wood waste) combustion to emit clean gas to the environment. In this experiment, gaseous emissions such as NO_X, CO, CO_2 will be analyzed. These three gases were chosen since they contribute to major pollution problems. Table 3 shows the emission results obtained from the combustion of wood waste.

Table 3
Gas emission (Wood waste)

Gas Emission from Wood Waste		
NO_X	56	ppm
SO_2	1	ppm
CO	33	ppm

The results of NO_X, CO and SO_2 emission level for wood waste were observed to be low <100ppm. This means that the produced gas from wood waste is quite safe and less harmful and has the potential to be commercialized [20]. Table 3 shows pure CO Syngas with less NO_X, SO_2 and CO emissions and will not harm human and the environment.

5. Conclusions

The combustion experiments have been successfully assessed using the wood waste as a feedstock, combusted with two types of gasification systems (downdraft and fluidized bed). The combustion performance of wood waste has been compared to the previous studies and showed the comparable and improved result.

The wall temperatures profile for burnt syngas produced from both gasifiers showed that the syngas produced via downdraft have higher temperature from 100mm until 500mm distance, however for fluidized bed; the temperature was much lower starting from 100mm until 800mm distance. This mean higher energy of a syngas was produced from the downdraft gasifier system where higher carbon conversion occurred during combustion as compared to fluidized bed.

The longest flame length produced from downdraft gasifier 12.8cm compared to that from fluidized bed 5.8cm. The higher carbon conversion in the downdraft system produced higher blowout energy supplied through the swirl gas burner.

In term of gas composition, the produced syngas can be classified as pure-CO syngas due to higher CO content 97.9% with very low H_2 content 0.04% result from the tests. In term of LHV value, the wood waste syngas produced 10.26 MJ/kg which is considered among the highest produced from biomass.

Based on results obtained from the experimental study, wood waste was found to have high potential as fuel replacement through proper methodology and gasification system. Wood waste was identified as one of the feedstock that can contribute for renewable energy.

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