

Pre-treatment of oil palm fronds biomass for gasification

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Abstract. Oil Palm Fronds (OPF) has been proven as one of the potential types of biomass feedstock for power generation. The low ash content and high calorific value are making OPF an attractive source for gasification. The objective of this study is to investigate the effects of pre-treatments of OPF residual on gasification. The pre-treatments included the briquetting process and extensive drying of OPF which are studied separately. In briquetting process, the OPF were mixed with some portions of paper as an additives, leaflets, and water, to form a soupy slurry. The extensive drying of OPF needs to cut down OPF in 4-6 cm particle size and left to dry in the oven at 150°C for 24 hours. Gasification process was carried out at the end of each of the pre-treated processes. It was found that the average gas composition obtained from briquetting process was 8.07%, 2.06%, 0.54%, and 11.02% for CO, H₂, CH₄, and CO₂ respectively. A good composition of syngas was produced from extensive dried OPF, as 16.48%, 4.03%, 0.91%, and 11.15% for CO, H₂, CH₄, and CO₂ contents respectively. It can be concluded that pre-treatments improved the physical characteristics of biomass. The bulk density of biomass can be increased by briquetting but the stability of the structure is depending on the composition of briquette formulation. Furthermore, the stability of gasification process also depended on briquette density, mechanical strength, and formulation.

1 Introduction

Oil palm frond (OPF) is an agricultural by-product that is abundantly available in Malaysia. Its low ash content and high calorific value have made OPF a good source of biomass energy via gasification [1]. However, utilization of OPF as a feedstock for bioenergy is limited [2]. Oil palm industry generates numerous type of biomasses, which are different in particle size and density. Among these, small particle sizes and low-density biomasses are not suitable for gasification. Because low bulk density biomass often encounters with bridging in gasification process [3]. Furthermore, low densities of feedstock are also difficult to transport, store, and interface with bio-refinery feed systems [4]. Bridging in gasification process significant

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effect on pressure drop, performance, and its slow down the movement of the biomass down to the gasifier system. Insufficient flow of biomass under gravity which eventually affect the on gas quality, and low heating value of produce gas [5]. To improve the low-density of feedstock through the densification processes such as; pelletization and briquette are effective techniques which make low-density feedstock suitable for the gasification process [4]. The aim of this study is to investigate the effect of pre-treatments of OPF residual on the gasification process.

2 Materials and methods

2.1 Characterization and feedstock preparation for briquetting

The ultimate analysis of OPF residual was carried out using CHNS analyzer as per ASTM D3176-09 standard procedure [6] to determine the percentage of carbon (C), hydrogen (H), nitrogen (N), sulphur (S), and oxygen (O) contents in feedstock that are important for stoichiometric air calculation of gasification process. The results of ultimate analysis of oil palm fronds residual are presented in Table 1.

Table 1. Ultimate Analysis of Oil Palm Fronds Residual

Feedstock	C (%)	H (%)	N (%)	S (%)	O*(%)
OPF	41.33	5.30	0.22	0.22	52.93
OPF Leaflet	41.20	4.81	2.89	0.34	50.76

The raw OPF was collected from oil palm plantation and shred in the shredder. The shredded feedstock obtained from shredder was not uniform in particle size. Therefore, sieving was done to separate different particle sizes of the OPF feedstock. The shredded feedstock of OPF obtained after shredding and sieving operation is shown in Figure 1. The first sieving process involved with 10 mm sieve size. The shredded OPF was poured onto the 10 mm sieve. The second sieving process involved with 5 mm sieving size. Briquette was formed from the mixture of the OPF fibre, OPF sawdust, and diced type OPF. The briquette process was done in two batches. In the first batch, sawdust, fibre, leaflet of OPF, and paper were used. While in the second batch of briquette, diced OPF was used instead of fibre, and a paper was neglected for the second batch. Approximated 4-5 liters of water was added to the mixture to form the soupy slurry. The mixture was then left for about an hour to allow it blend well.

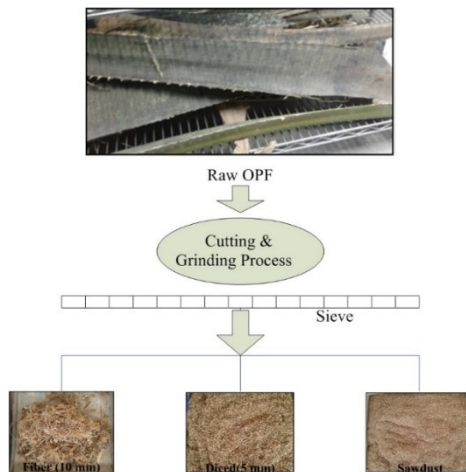


Fig. 1. Feedstock preparation for briquette formation

2.1.1 Forming briquette

The briquetting process was started after about an hour of soaking time. About 250 grams of the mixture was taken each time to fill the briquette mould. The mixture needed to be distributed evenly in the mould. It was to create the same pressure distribution when pressing was started. The pressing method was applied manually using the hand. The handle of the briquetting machine had to be pressed downward to remove the water content of the mould. The weight of the die used to press the mould was 8.0 N. The mould was left for 5.0 minutes under pressure to make sure all the water content was removed from the mixture. After 5.0 minutes, the briquette can be taken out. This process needs to be done carefully to make sure the structure of the briquette did not destroy because of the soft structure of the briquette. The handle of the level needs to be pulled upward to remove the briquette from the mould and left it for drying.

2.1.2 Extensive drying of OPF

OPF extensive drying was done to investigate the effect of moisture removal on syngas composition for gasification process. The drying was done at the temperature of 150°C for 24 hours using the electric oven. The particle size was 4-6 cm was used for extensive drying. Before the extensive drying, the raw OPF was naturally dried under the sun for 1 to 2 days after chopped down.

2.1.3 Gasification procedure

A downdraft and updraft gasifiers were used for gasification. OPF briquette and extensively dried OPF was used as a solid fuel for gasification. Around 6 kg of feedstock was fed into the gasifier for each run. A controlled air was supplied to the gasifier as a medium of gasification at a rate of 180-220 LPM by using a blower. The temperature of different zones of gasifier was monitor and recorded by Type K thermocouples and data logger profiles. Syngas compositions recorded at 1-minute interval along the 60-minutes of gasifier operation using X-STREAM online gas analyzer.

3 Results and discussion

3.1 Briquette properties

Briquettes produced from different OPF wastes, paper, and oily sludge at varying blending ratio and formulation of briquettes are presented in Table 2. More amount of OPF diced in blend producing more rigid, denser and stronger briquettes. The presence of oil palm leaflet in blend improved the surface contact of materials during press and shredded paper into the blending act as a binder material to help retain the moulded shape after briquetting operation. The physical shape was recorded as 10.5 cm in diameter and 2.5 cm in thickness, the inner diameter of the hole was 3.0 cm physical structure of the briquette is shown in Figure 2.

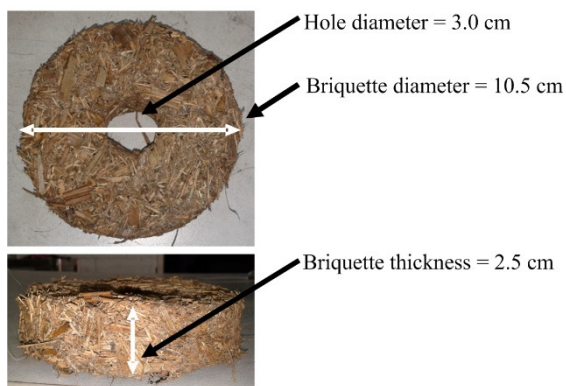


Fig. 2. Physical structure of a fully-dried briquette

The specific density of briquette on the dry basis was measured as 40 kg/m^3 . There was a significant difference between the wet and dry densities of the raw materials. Approximate 80% moisture removed during the drying process. The bulk density of raw blended feedstock was measured by dividing the mass of biomass with the volume of the container used. The volume of the container was recorded as $9.5 \text{ cm} \times 9.5 \text{ cm} \times 11 \text{ cm}$ in dimensions. The total mass of raw blended feedstock that filled up the container was 40 grams. The approximate mass of one dried briquette was in the range of 35-55 grams each. The wet condition of the biomass might influence the mass range of dried briquettes. The mechanical strength of dried briquettes was determined the stability and toughness of its structure tested by performing a drop test. Dried briquettes were dropped from a height of 1-2 m as conducted by Sing and Aris [7] in their tests. Both briquettes sustained their shape with minor damages after impact. Two more drop tests followed with each from a height of 5.0 m and 10 m respectively. The 1st batch of briquette was sustained its structure whereas, the 2nd batch found few cracks on the briquette after it was dropped from a height of 5.0 m while still maintaining its shape. The structure of 2nd batch of briquette was damage significantly after a drop from 10 m height. Therefore, it's proven that feedstock nature and formulation of briquette have an influence on its mechanical strength and density.

Table 2. Briquette Formulation

Biomass Type	Oil Palm Based Biomass (%)				Non-Oil Palm Biomass (%)	
	Sawdust	Fiber	Leaflet	Diced	Paper	Oily Sludge
1 st Batch of Briquette	37.00	14.80	7.50	N.A	3.70	37.00
2 nd Batch of Briquette	41.66	N.A	16.67	41.67	N.A	N.A

3.2 Gasification of briquette

The gasification of fully dried briquette of the 1st batch was carried out in downdraft gasifier [8] and 2nd batch was gasified in updraft gasifier. In downdraft gasifier syngas was produced but due to leakage in experimental setup syngas was unable to analyze. Results of syngas profile and temperature produced from the 2nd batch of briquette are presented in Figure 3.

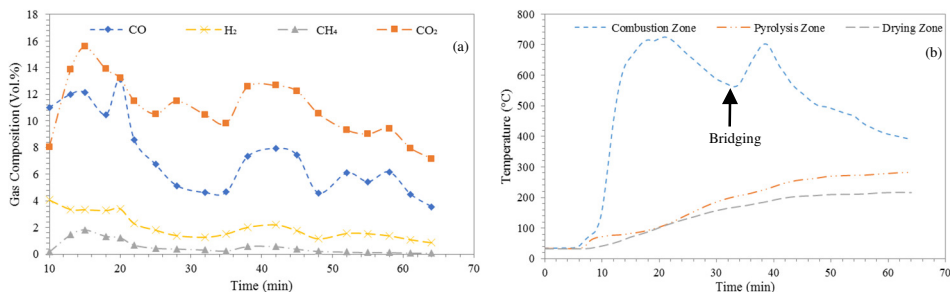


Fig. 3. (a) Syngas profile and (b) temperature profile produced during the gasification of 2nd batch of briquette

The average gas composition of process was recorded as 8.07%, 2.06%, 0.54%, and 11.02% for CO, H₂, CH₄, and CO₂ respectively. Comparison between gas compositions of briquette to typical OPF and extensive dried OPF as shown in Table 3. The Figure 3 exemplifies that the gases produced from briquettes were quite low due to the bridging that occurred during the experiment. The bridging occurred due to the low density of the particles from the briquette. As the structure of the briquette was not stable enough, as it was loaded into the gasifier, the briquette was broken into small particles. This contributed to the effect of low density to the operation. The low density of the biomass restricted the flow of the particles downward, and due to this, the gas cannot flow smoothly to the upper part of the gasifier [9]. By comparing the temperature profile of the process at the 32th minute, with the gas composition at the same duration of time, there is a drop in the production of gas and temperature. It occurred due to the bridging at that time. Onward from 35th minute of gasification, as the particles moving downward the gas production was increased.

Table 3. Gas composition produce from the pre-treatment methods and typical OPF gasification

Type of Feedstock	Average Gas composition (%)			
	CO	H ₂	CH ₄	CO ₂
Typical Gasification of OPF	18.02	10.00	1.40	10.03
Gasification of Briquette	8.07	2.06	0.54	11.02
Gasification of Extensive Drying of OPF	16.48	4.03	0.91	11.15

The temperature profile of the gasifier during briquette gasification showed a maximum combustion zone temperature of 650-700°C. The low combustion zone temperature may be insufficient to break the heavy carbon rings in the syngas. Dynamic syngas carried tar formed during the gasification process. The evidence of tar formation was observed at some spots of gasifier pipeline. The drying and pyrolysis zone temperatures were in the range of 200-300°C and were satisfactory to remove excess moisture and volatiles from the briquettes simultaneously [10].

3.3 Gasification of extensive dried OPF

Gas profile and temperature profile of gasification of extensive dried OPF presented in Figure 4. Good compositions of syngas were produced during the gasification process. The average value of CO, H₂, CH₄, and CO₂ was 16.48%, 4.03%, 0.91%, and 11.15% respectively. The peak gas composition was achieved between 12-20 minutes of gasification operation. After the 20th minute, all syngas components started decreasing especially CH₄. After 28th minute concentration of CO₂ was start increasing and drop in others gaseous components which were sign of combustion start insisted of gasification at the end of process. This phenomenon caused due to the decrease in feedstock amount after being consumed in

gasification. Whereas a constant amount of air was supplied to the system that shifted process of gasification toward the combustion due to change in air-fuel equivalence ratio that approaches to 1.0 [9]. The combustion zone temperature during the gasification of extensive dried OPF was found to be in the range of 450-650°C as shown in Figure 4b. The temperatures at drying and pyrolysis zones were found to be between 200-300°C respectively. No brigading was observed during the process.

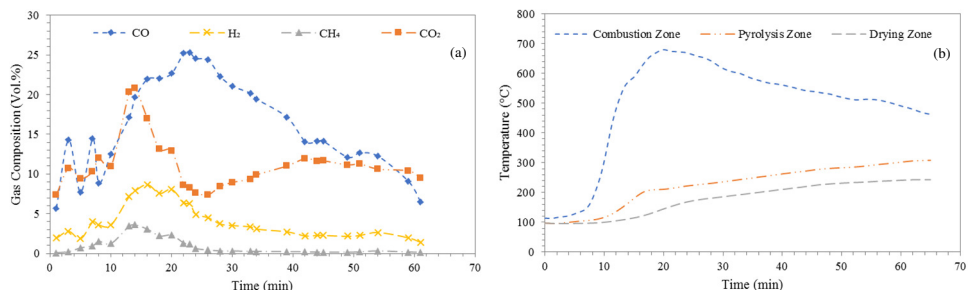


Fig. 4. (a) Syngas profile and (b) temperature profile produced during the gasification of extensive dried OPF

The comparison of the average gas composition of the two pre-treatment methods with the typical OPF gasification is presented in Table 3. The results of extensive drying method show a good potential in gasification operation as its average gas composition value are nearly approaching the average gas composition of typical OPF. For the briquette, the gas composition was lower due to the structure of the briquette that was not favourable and eventually creates bridging in the process due to the low density resulted from the broken.

4 Conclusions

Pre-treatment methods are very important in improving the physical conditions of the feedstock before being fed to the gasifier for the further gasification process. The experimental results show that bulk density of biomass can be increased by briquetting, however, the stability of the briquette structure depends on the formulation of the briquette. The extensive dried OPF improved the gasification process.

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