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Investigation on Gasification of Oil Palm Fronds, Challenges and Remedies

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Abstract
The basic characteristics of different feedstock materials to be used as fuel in a gasification process vary with the chemical and physical properties, bulk density, amount of fiber, moisture content etc. Hence the gasification potential of different biomass fuels needs to be investigated in terms of their suitability, performance and required preparation before gasification. This paper presents results of a preliminary study on the gasification behavior, potential, operational challenges (in terms of stability of operation, bridging, steam accumulation, and clinker formation) and their remedies for gasification of Oil Palm Fronds (OPF) feedstock. A simpler method of determining moisture content of OPF with a direct measurement of the density of a sample of the feedstock was developed. In addition, the equilibrium moisture content of OPF biomass was also determined. The axial temperature profile of the downdraft gasifier run on OPF feedstock was found to be in good agreement with literature values and investigation of stability of operation in terms of the dynamic temperature profile of the gasifier with operating time was found to be in the range of ±60 oC/min which was found to be satisfactory compared to literature. The study of variation of syngas heating value with operation time showed that the lower heating value (LHV) of syngas was found to be above 4 MJ/Nm3 (4.7 to 5.26 MJ/Nm3) throughout the stable operation time, which indicates satisfactory output comparable with that of woody biomass.

Keywords: *Syngas; lower heating value; gasification; biomass; palm oil residues.*

I. INTRODUCTION

The preparation of fuel in terms of collection, cutting to size, drying and storage is a crucial step for the gasification of biomass. The basic characteristics of different fuel materials vary with the chemical and physical properties, bulk density, amount of fiber, moisture content etc. A simple method of estimating moisture content of a given batch of feedstock undergoing drying, and equilibrium moisture content consideration (hygroscopic behavior) of OPF is highlighted. A detailed account of the experimental setup, operating procedures for gasification and tar sampling operations, with a discussion on measuring equipment and measurement methods need to be properly described. At the oil palm plantation, pruning of OPF is regularly done all year round during collection of fresh fruit brunches (FFB), as the fronds are naturally found surrounding the fruit brunches. The scope of feedstock treatment in this study includes cutting/chipping to proper size that is suitable for downdraft gasification, and drying under the sun or through several days of storage inside a room with natural ventilation.

The initial moisture content of freshly pruned green OPF biomass is high, normally above 70%. Hence, the feedstock needed to be dried to lower moisture content of 10 to 20% before being used as a fuel in downdraft gasification. It has been identified that the

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moisture content of the biomass affects both the operation of the gasifier and the composition of syngas [1], [2]. To make sure the feedstock was dried to the operable moisture content level, frequent moisture content measurement was carried out by taking a representative sample.

In additional, the characteristics of the fuel biomass are influenced by the origin of the biomass, but also by the entire supply system preceding any conversion step. Inconsistency of operating temperature, uneven gas flow and abrupt changes in air resistance throughout the gasifier lead to the degraded quality of the producer gas and therefore revealed poor gasification performance in the preliminary test [3]–[5]. Hence, the objective of this study was to identify the parameter that influence the gasification process either on the properties of the feedstock and the technical barrier during the operational process of the gasifier.

II. METHODOLOGY

Newly pruned and green OPF feedstock used for the study was collected from oil palm plantation site located at BotaKanan, Seri Iskandar, Malaysia. The pruned OPF inside the plantation could be categorized as freshly pruned ones which are green in color and those which had been left on the ground for longer period of time after pruning, which are usually brown in color. The brown fronds are more fibrous and lesser in weight due to partial drying as well as undergoing decomposition. The brown OPF are usually found difficult to cut to proper size as they are more of fiber and difficult to be chipped to the size appropriate for gasification. Hence the freshly pruned green fronds are cut to manageable size at the plantation, and transported to the lab where proper preparation took place. Size reduction was carried out making use of a chipping machine with the objective of producing particle size of feedstock suitable for downdraft gasification. Due to the slightly fibrous nature of OPF, cutting to proper size need to be carried out before drying. Once dried the fronds become more fibrous and cutting to size will be difficult. In addition, sharpening of the chipper blades and proper adjustment of the blade gaps was necessary in order to produce feedstock with less fibers and having clearly defined edges which are more suitable for gasification. The more challenging aspect of the feedstock preparation and which took longer time was drying. The chipping machine produces small blocks with dimension of the longer edge ranging from 5 to 50 mm. The smaller and partly dusty particles of size less than 10 mm, are difficult to work inside a fixed bed gasifier as they will be closely packed in the gasifier bed and prevent circulation of inlet air and gases through the bulk fill. Use of fine sized feed less than 10 mm dimension is also known to create increased pressure loss along the fuel bed and aggravate the problem of slagging [6]-[8]. Moreover, the slender and bigger size pieces of size larger than 50 mm produced by the chipper were found to be more fibrous and cause severe bridging inside the gasifier because of weightlessness and entanglement of fiber extremities. Therefore, a set of wire mesh sieves were used to remove the sizes less than 10 mm and those above 50 mm. Shown in Fig. 1 is a picture of feedstock of average size 20 mm and that of size lower than 10 mm. The feedstock used for the gasification was of average dimensions 20 mm square with 10 mm thickness.

(a)

(b)

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Figure 1. Different sizes of feedstock produced by chipping machine (a) average particle size of 20 mm (b) average particle size of 10 mm

The moisture content determination was carried out by drying the samples inside an oven for 24 hours at 105^{o}C. The initial moisture content of the samples was determined by measuring the initial and final weight of dried samples. Determination of moisture content of OPF feedstock using oven drying, before each gasification run was tedious and time taking. This calls for a simpler but reasonably accurate method of estimating the moisture content of a given batch of feedstock undergoing drying. To this effect, a method of estimation of moisture content of a sample through simple density measurement, without conducting 24 hours oven drying and measurement of weight loss, was proposed. Once such a correlation was developed the moisture content of OPF had been able to be estimated from a simple measurement of density of a representative sample. Considering the natural geometry of OPF, it can be observed that the fronds have three distinct sections (the hub, middle and tip sections). Fig. 2 shows the schematic of OPF depicting its three different sub sections. Considering variation of density and moisture content along the length of the frond, a total of 144 equal sized samples were prepared (48 from each of the frond parts namely the hub, middle and tip section). In order to correlate the moisture content of OPF with its density, the samples were dried to various moisture content values inside a laboratory oven and the corresponding density of each sample was measured. The density was easily determined from the mass and volume of sample. The sample volume was measured making use of a graduated glass container filled with a known volume of fine ash of size in the range of 1 mm. The volume difference before and after submerging the sample inside the sand was recorded and taken to be the volume of the sample. Finally, the average values of moisture content and density for the hub, middle and tip part of OPF and plotted as function moisture content versus density.

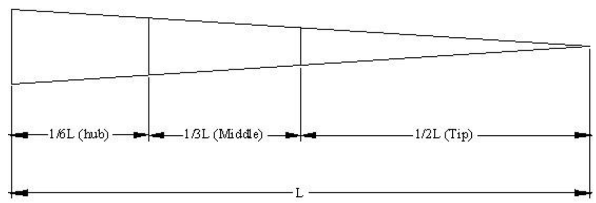

Figure 2. Schematic of OPF showing its three sections

A. *Reactor Design Considerations*

For high capacity and bigger grate diameter of downdraft gasifiers it is customary to incorporate both the radial air supply nozzles and additional central pipe line for inlet air supply. The objective of such arrangement is to make sure the air supply is properly distributed along the grate cross-sectional area in order to avoid blind spots on the grate which causes the pyrolysis products to directly pass the gasifier without being reduced by the glowing char bed. In this current fixed bed gasifier design both a central inlet air supply pipe as well as a side air supply pipe mounted on the wall was provided in order to ensure the uniform distribution of the hot oxidation zone along the entire reactor cross-section. The feed capacity of the gasifier is 12 kg with an average conversion rate of 10 kg/hr. The internal reactor dimensions of the gasifier are a height of 1000 mm and diameter of 400 mm, with overall external size of 450x450x1200 mm and a maximum weight of 120 kg. In order to decrease energy loss due to heat transfer, the gasifier wall was insulated with refractory cement material of thickness 25 mm. Detailed elaboration on the design of the gasifier unit is reported in the work of Moni et al., [9]. Gas chromatography (GC) machine was used to measure the composition of syngas produced by gasification in terms of volume concentration. The composition of CO, CO_2, CH_4 and H_2 was directly measured making use of a multipurpose EMERSON X2GP gas chromatograph. The measurement principles used by the GC are infrared measurement (IR), ultraviolet measurement (UV) and thermal conductivity measurement (TCM). The IR and UV measurement methods which use the principle of infrared/ultraviolet light absorbed by the sample gas were used to measure concentrations of CO, CO_2 and

CH_4. The wave length of IR/UV light characterized the gas components whereas the intensity of absorption was used for measuring concentration. The TCM principle which operates based on the unique thermal conductivity characteristic of the gas was principally used to measure H_2 concentration. The measuring accuracy of the GC unit used was ±2%. In addition, attached to the GC unit is a custom build gas conditioning unit consisting of condenser, 2 µm ceramic filter unit to remove particulates with liquid alarm system, diaphragm pump and peristaltic pumps assembled at the factory of the GC supplier. Shown in Fig. 3 is a picture of the gas analyzer system used for measuring the composition of syngas from the gasification experiments. The schematic of the gas conditioning unit depicting the operating principles and the various components is shown in Fig. 4.

B. Online Sampling and Gas Conditioning

The advantage of online sampling of syngas is that it avoids the variation and human error involved during manual injection of gas samples to the GC. Moreover, the online sampling enabled recording a number of syngas composition data at intervals of few minutes or even at any desired shorter intervals during the gasification. Since some percentages of water (moisture) and tar were expected to be produced from the gasification process, the gas conditioning unit attached to the GC has a condenser unit which condenses the gas to a temperature to lower than 5^{o}C. All condensates and tar from the condenser were drained through the condensate drain tubes provided before the gas passes through the ceramic filter of 2 micron rating for particulate cleaning as shown in Fig. 4. In addition, the ceramic filter was provided with a liquid alarm system to make sure that only dry gas passes to the GC detectors. Hence, the measured volume concentration (% Vol) of gas composition of syngas is considered to be on dry basis.

C. Syngas Cooling and Cleaning System

Gas cleaning ensures the supply of syngas with consistent gas qualities and heating value for downstream applications. A cyclone unit designed based on the estimated gas yield of the gasifier was used to carryout proper de-dusting and particulate removal prior to further cleaning. Moreover, a simple shell and tube heat exchanger was developed to cool the syngas from a temperature in the range of 200^{o}C at exit from the gasifier to a lower temperature of 40^{o}C. This cooling of the syngas assisted for collection of tar and condensates at subsequent filtering stage. Finally, oil bath filter unit was used to cleanse the syngas from tar and condensates.

Figure 3. Picture of online gas sampling and gas analyzer unit with calibration gas cylinders

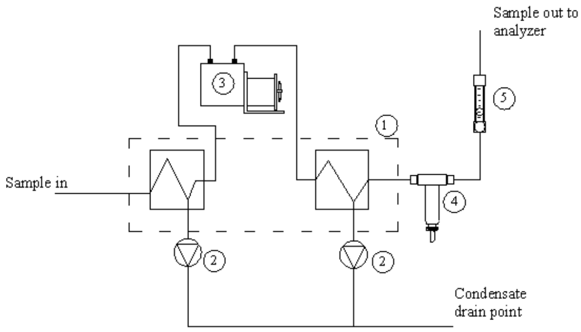

Figure 4. Schematics of gas condition unit: (1) Condenser, (2) Peristaltic pump, (3) Diaphragm pump, (4) Particulate filter with liquid alarm, (5) Rotameter for flow measurement

D. Gasifier Operation

In order to develop optimum and safe method of operation of the gasifier, and to put in place all necessary measuring instruments, a considerable amount of time and effort was spent during the initial development, testing and commissioning. The gasification experiments were conducted at average ambient conditions of 30^{o}C room temperature and 80% relative humidity. Pressure drops were determined across the gasifier and across the downstream cooling and cleaning units using a standard Dwyer manometer. Pressure of inlet air was measured to be 29 mm Hg, and the pressure inside the gasifier and on the exit pipe line after the cooling and cleaning units were 19 mm Hg and 15 mm Hg respectively. The total pressure drop across the whole system was measured to be 14 mm Hg (2 kPa). The measured total pressure drop for the experimental setup was found to be comparable with those reported in literature [10].

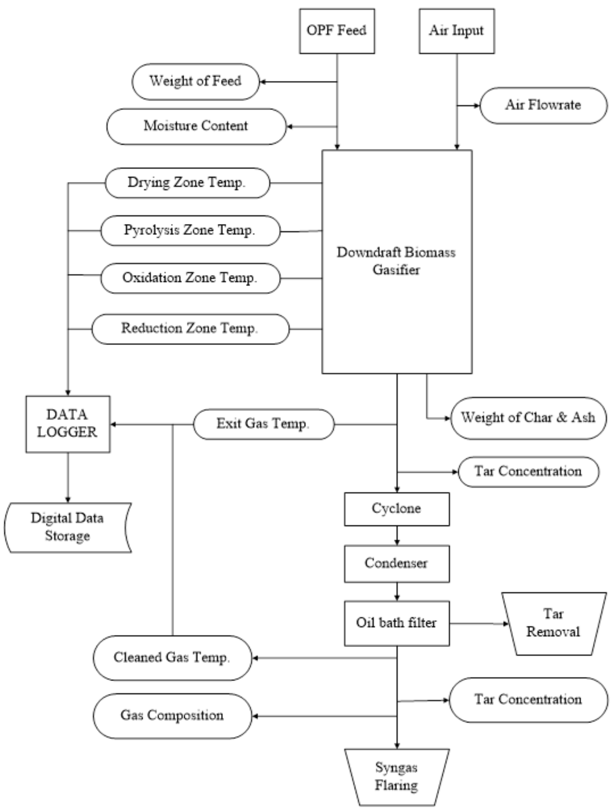

Figure 5. Detailed flow diagram of the experimental study

The main activities of operating and shutdown procedure include start up, data collection, shutting down and final cleaning of the gasifier. Startup involves operations like pre cleaning; filling the gasifier bed with fuel, and fixing of various measuring equipment. First pre-weighed amount of OPF feedstock was feed into the gasifier bed and the inlet air supply blower was started, and fuel was manually ignited at the grate level. Once stable operation was achieved and stable syngas production was ensured, a number of operating parameters were recorded throughout the operation time of the gasifier for each experimental run. The different operating parameters recorded include OPF feed rate, inlet air flow rate, gas composition measurement, tar and condensate generated, amount of char and ash produced, temperature and pressure measurement. The detail flow diagram of the operation of the unit and data collection procedures during the experimental run is shown in Fig. 5.

Shutting down involves all steps to be followed till the point where combustible gas was no more being produced and all running equipment like blower, computer, gas analyzer was switched off safely, after saving all necessary data collected during the operation run. Then the gasifier is let to cool down to safe temperature before the final stage of cleansing. Finally cleaning of the gasifier was carried out accounting for total mass balance of the gasification run by quantifying the amount of tar, char, and ash produced. The liquid tar and condensate inside the exit pipe line and the cyclone was drained and properly measured. The mass of char and ash collected from the grate were also measured and recorded.

III. RESULTS AND DISCUSSIONS

The initial moisture content of the samples was determined by measuring the initial and final weight of dried samples. The average initial moisture content of freshly pruned green OPF was found to be 70.04% on wet basis. Moisture content determination results for three samples is shown in Table I. Shown in Fig. 6 is a typical moisture loss curve for complete drying of an OPF sample. The drying was carried out using a CARBOLITE RHF 1600 drying oven while the weight loss was recorded every hour.

Table I Results for moisture content determination of OPF samples

Sample #	Initial weight (gm)	Final weight (gm)	MC (% wet basis)
1	18.72	5.89	68.63
2	17.38	5.28	69.64
3	17.76	5.00	71.87
Average			70.04

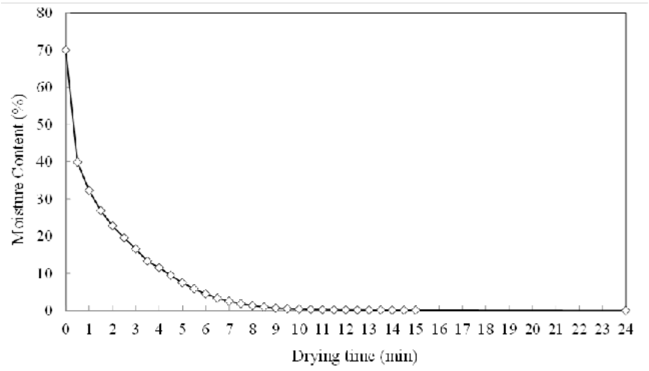

Figure 6. Variation of moisture content with drying time showing typical moisture content falling curve of OPF for oven drying

Shown in Fig. 7 is the moisture content versus density plot of the hub, middle and tip samples averaged values. As can be seen from Fig. 7, moisture content of OPF is highly correlated with its density. A second degree polynomial correlation function shown for the trend line was obtained with a satisfactory square of correlation coefficient value of 0.9282.

As it is common for other solid fuels, OPF feedstock stored in a certain temperature and humidity condition has a certain equilibrium moisture content value. This was investigated by keeping fully dried samples of OPF (i.e. oven dried samples at 105^{o}C for 24 hours and having moisture content of 0%), inside a naturally ventilated feedstock storage room at the lab. After keeping the samples for 48 hours, their moisture content was found to increase to a value of 12% (on wet basis). The average conditions of the storage room were a temperature 23^{o}C and relative humidity of 80%. On the other hand, OPF samples of higher moisture content stored inside the same environment were found to lose their moisture content to a value of 12% after several days. Shown in Fig. 8 is the percent moisture loss or gain of OPF samples. The equilibrium moisture content value which no longer showed either gain or loss is showed in Fig. 8 is around 12%. This shows that the minimum possible level of drying that can be achieved through natural ventilation inside the lab facility is only as low as 12%. To obtain a lower value of moisture content the use of some other means of drying like convention ovens is necessary. However, it is also deemed to notice that drying of OPF below 12% of moisture content is of no use unless the feedstock is intended for immediate processing for gasification, or else it is to be kept in a special storage facility where lower humidity and preferably higher temperature is retained.

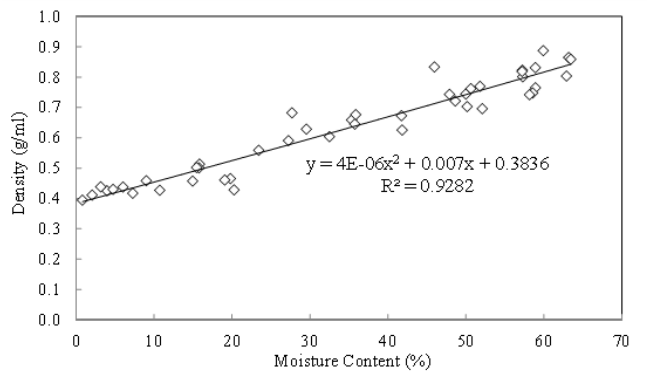

Figure 7. Density versus moisture content of OPF showing the correlation of moisture content and density

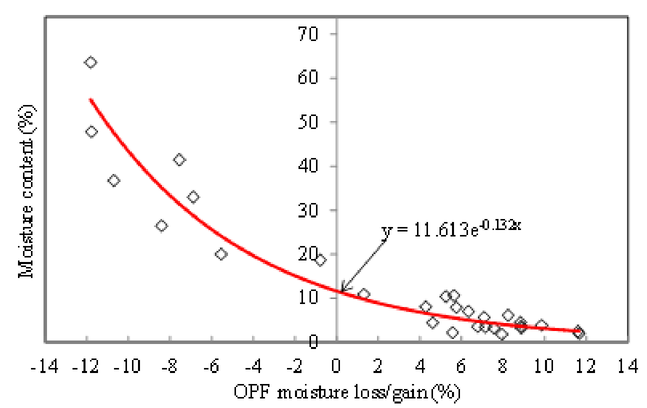

Figure 8. Equilibrium moisture content of oil palm fronds

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A. Influence of moisture content and axial temperature profile

Initial moisture content of OPF feedstock was observed to be the major parameter that influences the axial temperature profile of the gasifier. The effect of initial moisture content of feedstock on temperature profile was studied by using OPF feedstock with initial moisture content of 14%, 24% and 28% in different experimental runs. Fig. 9 shows the comparison of the axial temperature profile for different moisture content of fuel. The results indicated that for higher moisture content of feedstock 24% and 28%, the temperature profile was lower than the acceptable range for gasification operation as the peak oxidation zone temperature was found to be lower than 700°C. In addition, for fuel of moisture content higher than 20%, it was difficult to obtain a stable flare indicating lower moisture content is more suitable for downdraft gasification.

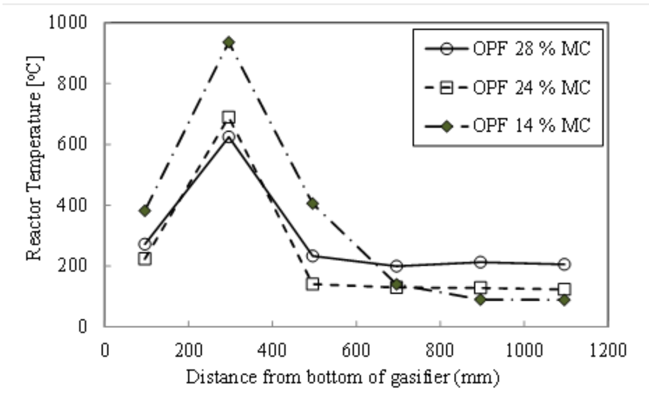

Figure 9. Variation of reactor temperature along the gasifier bed for different initial moisture content of OPF

Fig. 10 shows the axial temperature profile as a function of bed height for a typical gasification operation. Also shown in the figure are results from literature for comparison. Though there is no clear demarcation between the various zones, the axial temperature profile along the gasifier bed showed a typical downdraft gasification temperature profile signifying the temperature range for each zone of gasification. The temperature profiles reported in other studies [11]-[13]. The results of these studies were not directly comparable to the one in this work due to variations in the types of feedstock used and the gasifier design. Nevertheless, as shown in Fig. 10 the temperature profile for the current work and other similar studies for gasification of different biomass fuels are shown to be in close range and displayed a similar trend.

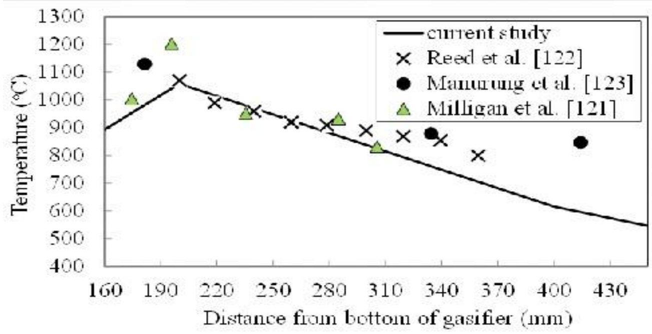

Figure 10. Comparison of axial temperature profile for downdraft gasification of OPF with literature results

B. Operational problems and remedies

During the initial gasification runs, problems associated with bridging were observed to occur. As the smooth flow of the feed is interrupted due to bridging, the grate will be starved for fuel causing the reactor temperature to drop rapidly. Therefore, the occurrence of bridging was evidenced by sudden drop in oxidation zone temperature. The occurrence of bridging was found to affect not only the reactor temperature but also the composition and heating value of syngas produced. One such evidence is shown in Fig. 11, where CO composition was found to drop sharply for operation duration between 20th to 25th minute and 45th to 65th. The effect of bridging is also demonstrated in Fig. 12, where variation of heating value and reactor temperature with operation time are plotted. It can be seen from Fig. 12 that the heating value of produced syngas shows direct correlation with the oxidation zone temperature. And it could be seen that heating value of syngas drops with the sharp decrease in the reactor temperature caused by bridging. To avoid the occurrence of bridging regular shaking of the gasifier was done to ensure smooth flow of fuel to the grate at all times.

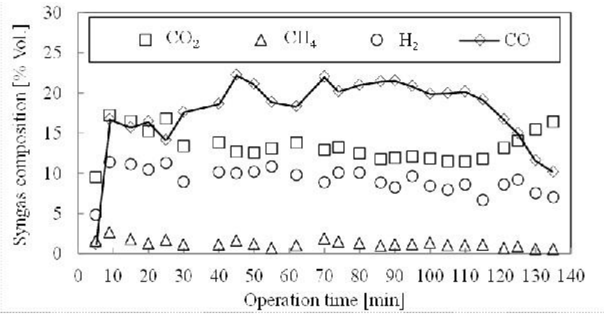

Figure 11. Variation of syngas composition with operation time showing effect of bridging on CO composition

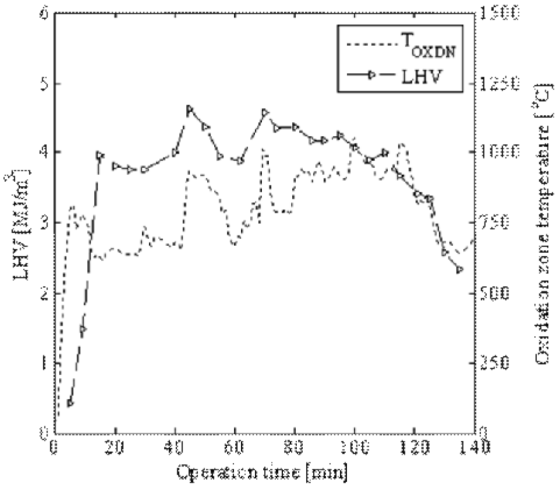

Figure 12. Variation of heating value of syngas and oxidation zone temperature with operation time showing effect of birding

C. *Steam accumulation*

The other major factor observed to cause sudden reduction of reactor temperature and affecting the gasification process was accumulation of steam released from the drying zone. Large amount of steam and condensate was found to accumulate at the top level of the gasifier, and as more and more steam accumulate near the top cover, it begins to condense and slowly start to flow down to the grate, affecting the combustion of fuel. As a result of this the reactor temperature was observed to start dropping sharply. The problem of steam accumulation was mitigated by opening an outlet valve at the top of the gasifier for a short interval of time to let out the accumulated steam. A more permanent solution would be providing a steam trap valve at the top position of the gasifier to let condensed steam out of the system, while preventing permanent gases from escaping through

D. *Ash clinkering*

The problem of ash fusion or clinkering was observed during experimental runs where the oxidation run temperature was recorded to be higher than 1200°C. Shown in Fig. 13 is a picture of clinker produced during downdraft gasification of OPF. Formation of ash fusion or clinkering during gasification is known to be caused by high reactor temperature that exceeds the fusion temperature of the mineral constituents in the fuel [14]. This indicates that the operating temperature needs to be kept at the level only sufficient to sustain the thermochemical processes. Cleaning of the grate from accumulated ash at the end of each gasification run was found to be successful in avoiding ash clinkering. In future, further studies need to be done on the ash fusion temperature and characteristics of mineral constituents of OPF to determine the exact safe reactor temperature value.

Figure 13. Picture of a sample of clinker or ash fusion produced at the grate

E. *Stability of operation*

Generally, as combustion inside the oxidation zone started, the reactor temperature in each zone of gasification would start to rise sharply during the first few minutes of gasification operation. Latter, as the operation became stable, temperature variation was observed to be minimal. Shown in Fig. 14 is the variation of the rate of change of temperature (dT/dt) with operation time, as a means to determine stability of the gasification process. As shown in Fig. 14, the

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oxidation and reduction zones experienced higher rates of change of temperature in the range of 300°C/min and 150°C/min, respectively during the first 10 minutes of the operation. At a later stage of operation, the rate of change of temperature in each zone was found to be in the range of ±60oC/min indicating a stable gasification operation. Similar trends of results were reported in the work of Barrio et al.,[15] for stratified downdraft gasification of woody biomass.

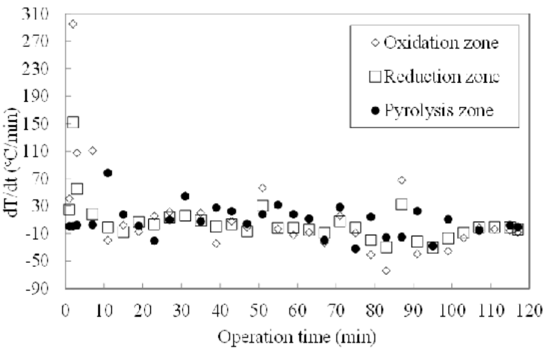

Figure 14. Rate of change of oxidation, reduction, and pyrolysis zone temperature with operation time

F. Variation of syngas composition with Operation time

Syngas composition with operation time for randomly selected experimental runs with equivalence ratio of 0.35 and 0.37, initial fuel moisture content of 16% and 15.21%, respectively is shown in Fig. 15 and Fig. 16. The results showed that the composition of CO increased steadily for the initial phase of the operation time and keep on decreasing for operation time after 70th minutes. The trend of CO_2 variation is quite the inverse of that for CO. This implies that the reactions for producing CO and CO_2 competed each other for the same reactant compounds as shown in Figs. 15 and 16. It can be seen from Fig. 15 that the concentration of H_2 in syngas showed a decrease from initial value of 11% at the start of gasification and average composition of 9.7% was found for the range of operation time between 30th and 90th minute. For the final 20 minutes of operation H_2 composition further decreased to an average of 6%. CH_4 composition was found to be relatively stable at an average value of 1.5% for operation time up to 50th minute and it decreased to a value of about 0.4% for operation time from 50th minute to 110th minute. After the 70th minute of operation as shown in Figs. 15 and 16, the composition of the fuel components showed a sharp drop. This is due to the fact that the feedstock in the reactor gets consumed during the initial 70 minutes of operation due to batch operation of the gasifier. Hence the stable gasification operation was taken to be 60th minutes duration from the 10th to 70th minutes of operation. The average gas composition values and calculated average heating value was taken for this portion of the operation time.

For batch fed gasification operation, the decrease in composition of H_2 and CH_4 at high operation time is expected as most of the volatile components produced by pyrolysis will be consumed during the first few minutes of operation. This leads to a decrease in composition of H_2 and CH_4 with time as most of the feedstock will be converted to char which is mainly composed of pure carbon. The general performance of the gasifier in terms of producing a fuel gas with sustainable and continuous composition could be achieved if continuous feed operation is used in a commercial gasifier.

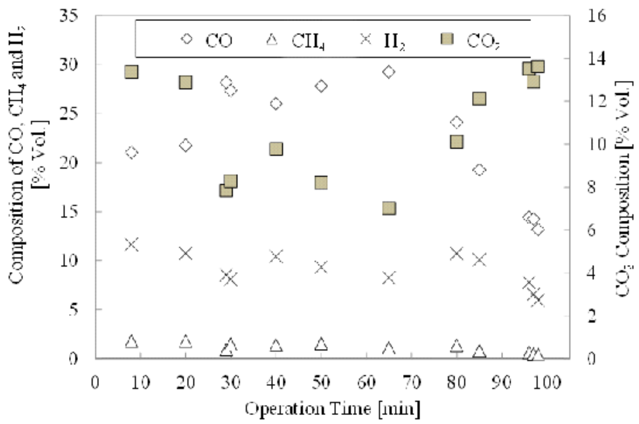

Figure 15. Variation of syngas composition (CO, CO_2, CH_4 and H_2) with operation time for a gasification run at equivalence ratio of 0.35 and MC of fuel 16%)

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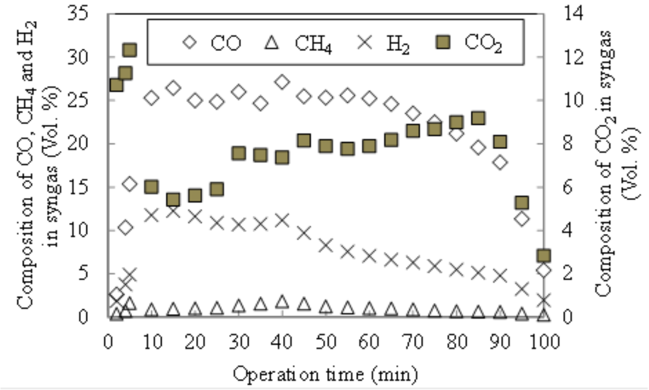

Figure 16. Variation of syngas composition (CO, CO_2, CH_4 and H_2) with operation time for gasification run at equivalence ratio of 0.37 and MC of fuel 14.21%)

Fig. 17 shows the variation of the combined composition of the fuel components of syngas (CO, CH_4 and H_2) with operation time for gasification at inlet air flow rate of 190 lpm. Generally, the composition of the fuel components of syngas CO, CH_4 and H_2, was found to start increasing in the first few minutes of operation and remain at a relatively steady level above 30% for about one hour of operation. An average and peak combined composition value of 36% and 40% respectively were obtained for the gasification run. Similar trends were observed for the other gasification run results.

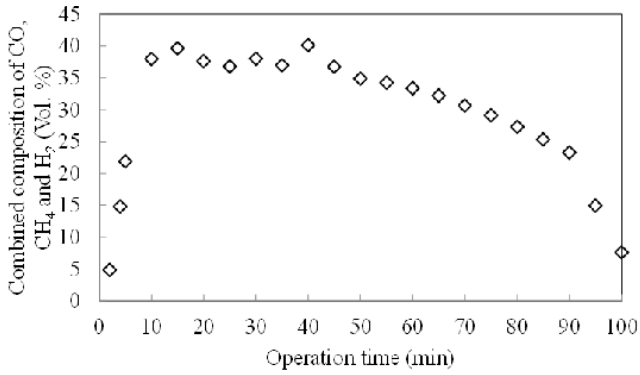

Figure 17. Variation of combined composition of fuel components of syngas (CO, CH_4 and H_2) with operation time

G. Variation of syngas heating value with operation time

Shown in Fig. 18 is variation of heating value of syngas and oxidation zone temperature with time. The oxidation zone temperature showed a sharp rise in the first 10 minutes of operation after startup, and both the heating value of syngas and oxidation zone temperature showed a steady increase till about the 70^{th} minute of gasification. The standard deviation of heating value for three number of data recorded corresponding to each operation time is shown by the error bars in Fig.18. The lower heating value (LHV) of syngas is shown to be above 4 MJ/Nm^3 (between 4.7 MJ/Nm^3 and 5.26 MJ/Nm^3) throughout the gasification until the 80^{th} minute, after which the LHV decreases sharply, most probably due to depletion of the feed material since the gasifier was under batch operation. As shown in Fig. 18 the reactor temperature increased sharply for the first 10 minutes of operation, as inlet air blower was started supplying more air and combustion commences. Considering the initial 10 minutes of startup where high rise of temperature was observed, and the sharp decrease in heating value and reactor temperature after the 70^{th} minute of gasification, the duration of stable operation was considered to be between the 10^{th} minute and 70^{th} minute of operation. The variation in heating value of syngas for the range of operation time between the 10^{th} and 70^{th} minutes was found to be minimal (a change of only 0.56 MJ/Nm^3), suggesting that stable operation was achieved. It can be deduced from the graph in Fig. 18 that an acceptable range of heating value of syngas (4-6 MJ/Nm^3) was produced during stable operation period of gasification.

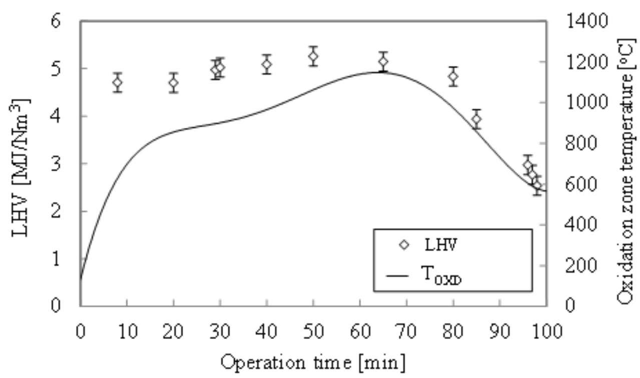

Figure 18. Variation of lower heating value (LHV) of syngas and reactor temperature with operation time for gasification run at equivalence ratio of 0.35 and fuel moisture content of 16%

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Conclusions

The study presented the operating challenges like bridging, stability of operation, and steam accumulation and clinker formation in gasification of OPF in a downdraft gasifier. In addition, the remedies for these highlighted challenges were presented. The potential of the gasification of OPF in terms of syngas composition and heating value of the OPF as the feedstock was evaluated. The axial temperature profile of the downdraft gasifier run on OPF feedstock was found to be in good agreement with literature values and investigation of stability of operation in terms of the dynamic temperature profile of the gasifier with operating time was found to be in the range of ±60 ^{o}C/min which was found to be satisfactory compared to literature. The study of variation of syngas heating value with operation time showed that the lower heating value (LHV) of syngas was found to above 4 MJ/Nm^3 (4.7 to 5.26 MJ/Nm^3) throughout the stable operation time, which indicates satisfactory output comparable with woody biomass.

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