EFFECTS OF DIFFERENT GASIFYING AGENTS ON SYNGAS PRODUCTION FROM OIL PALM TRUNK

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RAFIDAH J, SAKANISHI K, MIYAZAWA T, MOHD NOR MY, WAN ASMA I, MAHANIM SMA, SHAHARUDDIN H & PUAD E. 2011. Effects of different gasifying agents on syngas production from oil palm trunk. In Malaysia, the oil palm sector generates huge amounts of residues and wastes such as fruit fibres, palm kernel shells, empty fruit bunches, fronds, trunks and palm oil mill effluent. Oil palm trunk (OPT) is the most abundant biomass with high potential for energy and material source because oil palm trees are felled and replanted every 25 years. The biomass gasification was carried out in a gasifier using OPT to study its suitability as gasification feedstock. The experiment was carried out at atmospheric pressure 1 atm, constant temperature 900 °C and reaction time 60 min at different flow rates of gas into the gasifier. Effects of different gasifying agents on the producer gas composition especially syngas production ratio were studied. Various parameter conditions such as biomass feeding rate and gas supply flow rate were investigated. The syngas ratio (hydrogen content) increased when steam was used as gasifying agent compared with air due to water–gas shift reaction that occurred between carbon and steam to produce more hydrogen. The high nitrogen (N_2) content in producer gas could be reduced by replacing it with carbon dioxide (CO_2). CO_2 removal had no effect on greenhouse gases due to the recycling process of CO_2 during photosynthesis.

Keywords: Biomass, downdraft gasifier, producer gas, greenhouse gases

RAFIDAH J, SAKANISHI K, MIYAZAWA T, MOHD NOR MY, WAN ASMA I, MAHANIM SMA, SHAHARUDDIN H & PUAD E. 2011. Kesan agen gasifikasi ke atas penghasilan gas sintetik daripada batang kelapa sawit. Di Malaysia, sektor kelapa sawit menghasilkan kuantiti sisa dan bahan buangan yang banyak seperti serat buah, tempurung kelapa sawit, tandan buah kosong, daun, batang dan sisa buangan kilang minyak kelapa sawit. Batang kelapa sawit (OPT) merupakan biojisim terbanyak yang berpotensi tinggi sebagai sumber tenaga dan bahan mentah memandangkan pokok kelapa sawit ditebang dan ditanam semula setiap 25 tahun. Proses gasifikasi biojisim dilakukan di dalam mesin gasifikasi menggunakan OPT untuk mengkaji kesesuaiannya sebagai bahan mentah gasifikasi. Ujian dijalankan pada tekanan atmosfera 1 atm, suhu malar 900 °C dan masa tindak balas 60 min pada kadar halaju gas yang berbeza. Kesan agen gasifikasi yang berlainan ke atas komposisi hasil gas terutamanya nisbah penghasilan gas sintetik dikaji. Keadaan parameter lain seperti kadar kemasukan biojisim dan kadar halaju bekalan gas juga diselidiki. Nisbah gas sintetik (kandungan hidrogen) meningkat apabila wap air digunakan sebagai agen gasifikasi berbanding udara disebabkan tindak balas air kepada gas yang terjadi antara karbon dengan wap air untuk menghasilkan lebih banyak hidrogen. Kandungan nitrogen (N_2) yang tinggi dalam hasil gas dapat dikurangkan dengan menggantikannya dengan karbon dioksida (CO_2). Penyingkiran CO_2 tiada kesan ke atas gas rumah hijau akibat proses kitar semula CO_2 semasa fotosintesis.

INTRODUCTION

Biomass fuels are carbon-neutral resources that do not increase the total amount of carbon dioxide (CO_2) in their entire life cycle because CO_2 emitted from biomass fuels are reused by plants for their growth, i.e. photosynthesis (Yukihiko et al. 2009). A total of 4.49 million ha of land in Malaysia is under oil palm cultivation, producing 17.73 million tonnes of palm oil and 2.13 tonnes of palm kernel oil (MPOC 2009). Malaysia is one of the largest producers and exporters of palm oil in the world, accounting for 11% of the world's oils and fats production and 27% of export of oils and fats (MPOC 2009). The economic life of an oil palm tree is about 25 years. Many large plantations are due for replanting now, hence huge quantities of oil palm trunks

(OPTs) are available. Oil palm trunks contain high moisture contents of between 60 and 300% depending on the height and age of the palms. The carbohydrates constitute approximately 46% of the OPT.

Among the renewable energy sources available in the near future, biomass is expected to be one of the most attractive potential feedstocks for an alternative liquid fuel because of its carbon neutrality and abundance. Therefore, it is important to develop a technology to convert woody biomass into liquid fuels (Hanaoka et al. 2008). Biomass gasification is one of the famous conversion technologies to convert solid fuel into a combustible gas. A limited supply of oxygen (O_2), air, steam or a combination of the above serves as the oxidising agent. The product gas consists of carbon monoxide (CO), CO_2, hydrogen (H_2), methane (CH_4), trace amounts of higher hydrocarbons (ethene, ethane), water, nitrogen (N_2) (with air as oxidant) and various contaminants such as small char particles, ash, tars, higher hydrocarbons, ammonia, acids, alkalis and the like. Syngas or synthetic gas is a mixture of H_2 and CO gas with a specific ratio (Knoef 2008). Syngas can be used to synthesise different types of biofuels such as Fischer-Tropsch (FT) fuels, methanol, dimethyl ether (DME), mixed alcohols and even pure H_2.

Gasification process involves four different processes which are drying, pyrolysis, oxidation and reduction (Knoef 2008). In complete combustion, CO_2 is obtained from the carbon and water from the H_2. Oxygen from the fuel will be incorporated into the combustion products, thereby decreasing the amount of combustion air needed. Combustion, occurring in the oxidation zone, and temperature will decrease during the reduction (Knoef 2008).

Steam is one of the gasifying agents that is normally used in the gasification process. The introduction of steam as a gasifying agent during gasification has been shown to enhance H_2 production from a variety of fuels that include coal, biomass and municipal solid waste (Butterman & Castaldi 2008). It can produce more H_2 compared with gasification processes performed without steam. The fact that high molecular weight hydrocarbons are subjected to thermal cracking and consequently formation of additional H_2 can attribute to this situation. If the products obtained from steam gasification processes are compared, more gaseous products are obtained. However, the presence of steam as an agent slows down the rate of gasification (Haykiri-Acma & Yaman 2007).

This paper studies the effects of different height portions of oil palm trunk and gasifying agents on syngas production. Felled oil palm trunk was used as biomass feedstock to be converted into combustible gas using downdraft fixed-bed gasifier. Five types of gasifying agents were used, i.e. air, steam–O_2, O_2–CO_2, steam–O_2–CO_2 and steam–air.

MATERIALS AND METHODS

Biomass feedstock

OPT residues used as feedstock in the gasification process was obtained from a plywood mill in Kluang, Johor, Malaysia. The OPT material was taken from the core of the trunk after the outer part was converted into veneer. The OPT was cut into three different height portions, namely, top, middle and bottom, and labelled. Each portion was shredded using machine and oven dried at 100 °C (overnight). The shredded OPT was ground and sieved to obtain particle sizes between 500 µm and 1 mm.

The characterisation of OPT was carried out where the proximate analysis was conducted following ASTM E870 (ASTM 2006) for determination of moisture content, ash, volatile matter and fixed carbon contents. The moisture content of OPT was determined using a moisture analyser. The ultimate analysis of OPT was performed using an elemental analyser and ion chromatograph.

A downdraft fixed-bed gasifier was used in this study. Air, steam, O_2 and CO_2 were used to study the effects of different types of gasifying agents on the gasification process. Air consists of O_2 and N_2 with standard ratio 21:79. Figure 1 shows the schematic diagram of a gasifier. The gasification unit consists of a furnace, a quartz reactor (length 750 mm and i.d. 26 mm), thermocouple to control the top and bottom temperatures, screw feeding machine to supply the specified amount of feedstock into the reactor, mass flow controllers to supply gases (gasifying agents) such as O_2, air and CO_2, a pump and steam generator to supply steam, liquid collector to trap the tar produced, wet gas flow meter and gas collection bag.

The reactor and furnace temperature was set at 900 °C. The actual temperature inside the
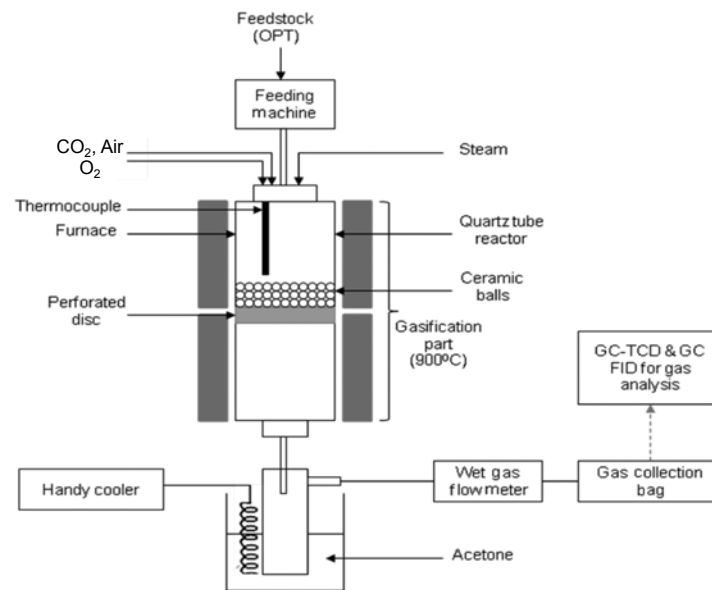
Figure 1　Schematic diagram of gasification unit

reactor was measured using the thermocouple. The perforated disc was placed inside the reactor with length from the perforated disc to the top of reactor about 65 cm. Within this area, the combustion and reduction processes would occur. On the perforated disc, aluminium balls with diameter 4 mm were placed to trap the char of biomass (Hanaoka et al. 2009).

During the gasification process, the temperature was maintained at 900 °C and the reaction time was set at 60 min. The gas was collected every 10 min for 5 min. The gas collection started at t = 5 min. However, the process only reached steady state after 15 min.

The biomass feeding rate ranged from 0.12 to 0.16 g min^{-1} at eight constant flow rates of the gasifying agent. The O_2 flow rate for air and steam gasification was maintained at 40 ml min^{-1}. The N_2 or CO_2 flow rate was maintained at 150 ml min^{-1} either for air (O_2–N_2) gasification or O_2–CO_2 gasification. The total flow rate of gases supplied into the reactor was about 190 ml min^{-1}. For steam gasification, the temperature of steam used was 150 °C while the steam flow rate varied from 0.060 to 0.30 ml min^{-1} depending on the parameter set up for the experimental work.

Gas composition analysis

The producer gas formed during the gasification process was collected in gas collection bags. The gas was analysed using gas chromatography (GC) with

thermal conductive detector (TCD) and GC with flame ionisation detector (FID). For GC–TCD, two types of columns were used with molecular sieves 5A and Propak Q. The oven temperature was 70 °C and injector/detector temperature, 100 °C. The gas analysis took about 15 min. While for GC-FID, squalance column was used. The column temperature was 40 °C and the injector/detector temperature was 200 °C. This GC temperature would increase from 40 to 200 °C during analysis of sample for the duration of 45 min. The GC was cooled down to 40 °C first before the next sample was analysed. The solid residue remained on the aluminium ball was identified as char. The weight of char remaining after the process was also determined. The tar content in the liquid collector was filtered to separate it from the acetone liquid. The tar residue was then oven dried overnight to obtain the amount of tar produced.

RESULTS AND DISCUSSION

Characterisation of oil palm trunk

Table 1 shows the proximate and ultimate analyses of the different portions of OPT. Sample A1B2 (bottom) contained high carbon (44.14%) compared with the other portions. Sample A3T2 (top) contained more parenchyma that was easily burned and thus produced more ash. It also contained less fibre that produced less carbon

compared with the bottom sample. There was no sulphur in OPT and only a small amount of N was detected.

Syngas ratio at different heights of oil palm trunk

Comparison of syngas ratio at different height portions of OPT using air and steam–O_2 is shown in Table 2. The highest syngas ratio obtained was 1.41 for sample A1B2 using steam–O_2 as the gasifying agent. The average syngas ratio for this sample was 1.33, about 85% increase in comparison with air for the same sample. This is because the introduction of steam had increased the H_2 content from 13.65 to 31.25% due to the water–gas shift reaction (Table 3).

Table 3 shows the producer gas composition in each OPT sample. The H_2 content was higher for samples using steam–O_2 as the gasifying agent. The H_2 contents varied between 13.10 and 31.25% for different gasifying agents and OPT samples. The N_2 content in the producer gas composition decreased more than 60% when steam–O_2 was applied. The purpose of minimising the N_2 content in the producer gas is that the absence of N_2 will affect the efficiency of FT-synthesis process to produce FT-diesel and other fuels. During steam–O_2 gasification, CO_2 content increased to 90% (based on average value) because CO had reacted with H_2O to produce more CO_2 and H_2 and at the same time reduced the N_2 content.

Table 4 shows the biomass conversion to producer gas, char, tar and loss (undefined char and liquid compound such as pyroligneous acid). Gas conversion was higher when using air gasification compared with steam–O_2 gasification due to the high amount of N_2 gas composition in the producer gas.

The char yield was below 10% for all samples regardless of air or steam–O_2 gasification. For air gasification, the char yields were higher than steam–O_2 gasification and were between 6 and 10%. Steam–O_2 gasification produced less char (below 5%). Tar yields were not more than 1% for both gasification processes. The percentage of loss using steam–O_2 was higher than air. This could be due to some of the undefined char remaining in the reactor that could not be taken into account and also small amounts of liquid produced during steam–O_2 gasification. For air gasification, the loss was less than 10% and for sample A2M2, loss was about 0.10% which meant that the gasification process was almost complete with 99.90% conversion. The presence of steam

Table 1   The proximate and ultimate analysis of oil palm trunk

Sample	Ultimate analysis (%)					Proximate analysis (%)			
	C	H	O	N	S	MC	VM	FC	Ash
A1B2 (bottom)	44.14	6.25	49.42	0.19	0.00	7.20	82.31	9.16	1.33
A2M2 (middle)	43.23	6.10	50.41	0.26	0.00	7.40	85.08	5.71	1.81
A3T2 (top)	43.26	6.14	50.36	0.24	0.00	7.00	80.21	10.33	2.46

C = carbon, H = hydrogen, O = oxygen, N = nitrogen, S = sulphur, MC = moisture content, VM = volatile matter, FC = fixed carbon

Table 2   Syngas ratio for different portions of oil palm trunk

Reaction time (min)	Sample					
	A1B2 (Air)	A2M2 (Air)	A3T2 (Air)	A1B2 (Steam–O2)	A2M2 (Steam–O2)	A3T2 (Steam–O2)
15	0.69	0.67	0.70	1.18	1.30	1.04
25	0.75	0.72	0.73	1.30	1.29	1.31
35	0.75	0.75	0.73	1.36	1.38	1.28
45	0.73	0.76	0.73	1.37	1.31	1.29
55	0.68	0.77	0.74	1.41	1.29	1.27
Average	0.72	0.73	0.73	1.33	1.31	1.24

Table 3   Producer gas composition (%)

Gas/Sample	A1B2 (Air)	A2M2 (Air)	A3T2 (Air)	A1B2 (Steam–O_2)	A2M2 (Steam–O_2)	A3T2 (Steam–O_2)
H_2	13.65	13.10	15.40	31.25	27.42	26.29
CO	19.22	18.14	21.39	24.13	21.24	21.54
CO_2	12.07	14.11	10.24	20.70	24.34	24.37
N_2	48.04	47.85	46.56	13.27	17.93	18.31
CH_4	3.59	4.61	4.13	7.15	5.98	6.18
O_2	2.60	1.07	1.23	2.05	1.84	1.98

A1B2 = bottom, A2M2 = middle, A3T2 = top

Table 4   Percentage of biomass conversion

Product	Sample					
	A1B2 (Air)	A2M2 (Air)	A3T2 (Air)	A1B2 (Steam–O_2)	A2M2 (Steam–O_2)	A3T2 (Steam–O_2)
Gas conversion (%)	83.90	93.31	86.43	78.21	77.68	78.29
Char yield (%)	6.82	6.37	9.07	4.63	4.56	4.40
Tar yield (%)	0.39	0.21	0.19	0.17	0.35	0.83
Loss (%)	8.90	0.11	4.31	16.98	17.41	16.48

A1B2 = bottom, A2M2 = middle, A3T2 = top

in the gasification process reduced the present conversion rate and needed longer reaction time to completely convert the biomass into products.

Effects of different gasifying agents on syngas ratio

Sample A1B2 was selected for this study because it was found to produce the highest syngas ratio (Table 2). The syngas ratio obtained for steam–air was 1.40, only 5% higher compared with 1.33 obtained for steam–O_2 (Table 5). This value depends on the ratio of H_2 to CO in the producer gas after gasification process. The O_2–CO_2 gasification gave the lowest syngas ratio with an average value of 0.33, almost 76% lower than the steam–air syngas ratio. During this period, the carbon in biomass reacted with CO_2 to produce more CO in the producer gas.

Table 5 shows the syngas ratio and producer gas composition using different types of gasifying agents. The syngas ratios for steam–O_2 and steam–air were higher than the others. However, the H_2 content for steam–O_2 was 35.52%, higher than the steam–air (19.53%). During steam–O_2

gasification, water–gas shift reaction occurred where CO reacted with steam (H_2O) to produce more H_2 and CO_2. The difference was almost 1.8 times or 81.9%. Since our main purpose was to produce more H_2 in the producer gas, using steam–O_2 was the best gasifying agent. A high amount of H_2 in the producer gas is very important because H_2 is being used more than CO in many chemical reactions to produce biofuels either through FT-synthesis or methanol synthesis. For the N_2 content, its percentage decreased to below 5% when air was not used as a gasifying agent.

The CO content was high during O_2–CO_2 gasification. During this process, more CO was produced (C + CO_2 → 2CO). CO_2 content was the highest using steam–O_2–CO_2 gasification. However, CO_2 can be removed during the gas cleaning process to obtain a higher value syngas. More CH_4 was produced during steam–O_2 gasification at about 7.9% compared with 3.3% for O_2–CO_2.

Comparing air gasification and steam–air gasification, the syngas ratio was found to have increased by 94.4% that of air gasification. This was because the water–gas shift reaction resulted

in the increase of H_2 content by 29.4% and the decrease of CO content by 33.3%. The CO reacted with water to produce CO_2 and H_2 which caused the CO_2 content to increase by 39.2%.

Comparing O_2–CO_2 gasification and steam–O_2–CO_2 gasification, the syngas ratios for O_2–CO_2 and steam–O_2–CO_2 were 0.33 and 0.66 respectively (Table 5). This showed 100% increase. This is due to the reaction of biomass with CO_2 to produce more CO. When steam was supplied together with O_2–CO_2, the CO content decreased by 41.4% from 30.10% to 17.63% and H_2 content increased by 17.5% from 9.91 to 11.64%. The CO_2 and N_2 contents were also affected with CO_2 increasing by 18.1% and N_2 decreasing by 3.7%. This gasification process could be improved by introducing more steam to produce more H_2 and at the same time increase the syngas ratio.

Table 6 shows the biomass conversion percentage when different gasifying agents were used. The gas conversion percentage was high when CO_2 was applied, i.e. exceeding 90% either with O_2 or steam–O_2. This is because the use of CO_2 as gasifying agent can reduce the N_2 content and produce clean gas with high CO_2 content. Indirectly gas conversion percentage would increase parallel with carbon conversion when CO_2 was applied. Only 70% gas conversion was obtained for steam–air. The char yield was highest when using air and lower when using CO_2. The application of CO_2 had decreased the char content after the gasification process. This is because the char reacted with CO_2 to produce more CO. The percentage of loss for steam–air was high, 23.84% compared with air, 8.90%. The introduction of steam caused the water–gas shift reaction to occur and this process could be reversed to produce water and CO.

CONCLUSIONS

Biomass gasification of OPT as feedstock was carried out using air, steam, O_2 and CO_2 as gasifying agents. The syngas ratio for steam–O_2 was higher than air gasification. Steam played an important role in this process which introduced the water–gas shift reaction to produce higher amounts of H_2 in the producer gas. The N_2 content in the producer gas could be minimised when CO_2 was used to replace N_2 in air. The N_2 had decreased by 91.6% from 44.82 to 3.75% when CO_2 was used. However, the syngas ratio had decreased from 0.72 to 0.33% because CO

Table 5 Syngas ratio and producer gas composition (%) for sample A1B2

Gas	Gasifying agent				
	Air	O_2–CO_2	Steam–O_2	Steam–O_2–CO_2	Steam–Air
Syngas ratio (H_2/CO)	0.72	0.33	1.33	0.66	1.40
N_2 (%)	44.82	3.75	4.72	3.61	43.30
CO (%)	20.97	30.10	26.82	17.63	13.99
H_2 (%)	15.09	9.91	35.52	11.64	19.53
CO_2 (%)	13.19	51.69	23.24	61.03	18.36
CH_4 (%)	3.65	3.28	7.85	4.87	3.50

Table 6 Percentage of biomass conversion for sample A1B2

Product	Gasifying agent				
	Air	O_2–CO_2	Steam–O_2	Steam–O_2–CO_2	Steam–Air
Gas conversion (%)	83.90	90.54	78.21	93.83	70.24
Char yield (%)	6.82	1.52	4.63	1.01	5.71
Tar yield (%)	0.39	0.10	0.17	0.11	0.21
Loss (%)	8.90	7.84	16.98	5.05	23.84

content had increased by 43.5% from 20.97 to 30.10%. During steam–O_2–CO_2, the syngas ratio increased from 0.33 to 0.66 compared with O_2–CO_2. The CO content had decreased by 41.4% and H_2 content increased by 17.5%. This composition could be increased if more steam was introduced in the gasifier. Overall, gasification using steam–O_2 was the best agent to produce high syngas ratio and high amounts of H_2. OPT was found to be a suitable gasification feedstock.

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