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A Review of Palm Oil Biomass as a Feedstock for Syngas Fuel Technology

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Abstract

Fossil fuel as the world dominated energy source is depleting and posing environmental issue. Therefore, Synthesis gas (or syngas) which serve environmental clean fuel characteristic is expected to play a major role as one of the potential renewable energy in the future. Syngas, produced from solid feedstock (such as biomass, coal, refinery residual, organic waste and municipal waste) via gasification process can be used directly as fuel for power generation. Besides, syngas also acts as key intermediary to produce transport fuel depending on their quality. The chosen feedstock for syngas production determines the composition and heating value of the syngas produced and hence will be reviewed in general. This paper then review critically palms biomass as the potential source of feedstock for syngas production, as it is widely accessible in the context Malaysia. Palm biomass presents a solution that is sustainable and eco-friendly that is yet to be fully capitalized in the palm oil industry. Some of the palm biomass including oil palm frond (OPF), empty fruit bunch (EFB) and palm kernel shell (PKS) are identified to contain high heating value which indicate their potential use as solid biomass feedstock for syngas production.

Keywords: Syngas; palm oil biomass; oil palm frond (OPF); empty fruit bunch (EFB); palm kernel shell (PKS)

1.0 INTRODUCTION

Integrated Gasification Combined Cycle (IGCC) power plant is one of the significant syngas applications in power generation.[1] Improvements in gas turbine efficiency and reliability have made syngas a viable fuel for electric power generation using IGCC.[2] However, variation of syngas composition can become a challenge in designing syngas combustor and applying syngas fuel.[3] Syngas composition varies depending on the type of fuel sources and production process technique and method[3]. There are many types feedstock that can be used to produce syngas, some of which are found in abundance, such as biomass, coal, refinery residual, organic waste and municipal waste.[4] Among all, biomass offers considerable opportunity of major renewable, sustainable and environmental-friendly energy sources.[5] Biomass is the fourth most prevalent energy sources after coal, oil and natural gases; and presently supplies for about 14% of the world's total energy consumption.[6]

Agricultural sector contributes 12 % to Malaysia's Gross National Income (GNI), a significant amount that makes agricultural-derived biomass abundantly available as feedstock for syngas production. Malaysia is the world second largest producer of crude palm oil, accounting for about 8% percent of GNI, with a value over RM53 billion.[7,8] Most of the palm biomass is either landfilled as waste or left on plantation on ground for mulching as organic fertilizer.[9] There is a lack of initiative to process these biomass to become value added downstream product due to a lack of available efficient processing technology and poor management.[9,10] One potential use of palm biomass is as co-firing fuel in boiling system. However, most boiler system installations in Malaysia are still operating with low-pressure boilers with less than 40% overall cogeneration efficiency.[10] Almost 77% of oil palm mills in Malaysia use combustion system with high CO2 emissions.[10] Therefore, gasification system along with CHP (combined and heat power) is one potential technology that can replace conventional system to improve the biomass conversion efficiency as well as reducing carbon emission.

Understanding the characteristic of biomass to produce syngas is important to investigate the potential of syngas to be used as renewable energy in Malaysia. Therefore, this study will review the availability, current state, characteristic and potential of palm biomass as solid fuel feedstock to produce syngas.

2.0 PALM BIOMASS AS A POTENTIAL RESOURCE OF MALAYSIA'S SYNGAS

Syngas derived from biomass is expected to play a major role in the future since Malaysia has huge production of biomass due to higher agricultural activities. Considering that the palm oil industry is the largest producer of biomass in Malaysia. The Malaysian palm oil industry generates 80 million dry tonnes of solid biomass per annum.[8] Oil palm biomass contributes 85.5% of the total biomass that is available in the country.[11] Approximately only 10% of palm oil is produced from each of oil palm in Malaysia and the remaining 90% is biomass residue including fronds and trunks.[12] Palm oil residues are generally produced as by product from milling sector and plantation activities. The palm kernel shells (PKS), mesocarp fibers (MF), and empty fruit bunches (EFB) are the main residues produced during the milling process to produce crude palm oil (CPO).[13] Meanwhile, the oil palm fronds (OPF) and oil palm trunks (OPT) are the major residues obtained from the plantation during cut-down. Fronds are also obtained during harvesting and pruning.[14] Table 1 shows the weight proportion and quantity per hectare for the different types of oil palm biomass in Malaysia. Currently, three quarters of solid biomass are used to produce fertilizer and for mulching purposes (to improve fertility) in plantations.[10] Therefore fronds and trunks commonly remain in the plantation while EFBs are return to plantation from the mills.[15,16] Mesocarp fiber, palm kernel shells and some EFBs from the milling waste are commonly utilized for local steam power generation.[16] Some of the biomass is used for wood industry, animal feed and other niche downstream applications.[17] Some of the downstream applications of palm biomass like wood products, bioenergy and pellets are widely available and Malaysia is among the pioneering countries.[18,19]

However, biomass utilization is not as common in Malaysia as compared to Europe where it currently supplies 6% of Europe's total energy needs.[20] Only 1.8% biomass was utilized in Malaysia as shown in Table 6.[21,22] In 2009, the National Renewable Energy policy and action was launched by federal government to enhance the utilization of renewable energy resources. This policy and action plan led to the enactment of the RE Act 2011 with feed-in tariffs included to provide a more attractive implementation of grid connected power generation from renewable energy resources.[23] New Renewable Energy Act 2010 revised the target to 985MW by 2015, 2080MW by 2020 and 21,000 MW in 2050.[23] The new feed-in tariff strategy give a potential market to syngas since syngas derived from biomass at producer gas stage is used in the power and heat generation industry.[24,25] Syngas can be used directly either in stand-alone combined heat and power (CHP) plant or by co-firing the producer gas in large-scale power plant.[26]

Table 1 The weight proportion and quantity per hectare for the different types of oil palm biomass in Malaysia[27]

Source of residue	Type of residue	Description	Weight of the total source (%)	Quantity per hectare (ton/ha)
Fresh fruit bunch (from palm oil mill)	Palm kernel shell	Remain after palm kernel oil extraction	5.5	1.1
	Empty fruit bunch	Remains after removal of palm fruits	22.0	4.4
	Mesocarp fiber	Remains after crude palm oil (CPO) extraction from fruit bunch.	13.5	2.7
Oil palm tree at Cut-down (from plantation)	Trunk[a]	Tree trunk available at end of plantation lifecycle	70.0	41.1
	Frond	Leaves branch	20.5	16.0
	Leaf	Leaves of oil palm tree	6.5	7.7
	Other	-	3.0	19.4
Oil palm tree at pruning (from plantation)	Frond[b]	Branch with leaves	27.0	10.0

[a]Palm trunk felled once every 25-30 years. [b] Consist of leaf and measured in dry weight

3.0 OIL PALM BIOMASS RESIDUE FOR ENERGY

Oil palm biomass can be converted to a wide range of value added products that can be divided into three main categories namely such as bio-based value added products, biofuel or as direct fuel for power generation.[28-29] Characterization of the chemical and phase compositions of a given solid fuel is needed before applying energy conversion processes to the biomass.[30] For that purpose, previous research commonly use structural composition, ultimate and proximate analysis for characterization of solids fuels to determine the properties and quality of biomass.[30,31]

Structural analysis provides information of lignocellulose content (cellulose, hemicellulose and lignin) which are important for the development of fuels and chemicals, study of combustion phenomena and estimation of HHV.[32,33] Ultimate analysis shows the mass percentages of N, S and Cl for environmental impact study; and C, H and O for estimation of heating value.[30,32] Proximate analysis helps to assess the mass percentage of moisture, volatile matter, fixed carbon and ash contents. Ash can cause ignition and combustion problems.[30] High volatility offers the advantage as a combustion feedstock such as lower temperature for decomposition process.[34] High fixed carbon and volatile matter increase the heating value.[32] The following sub-sections will review the characterization of some oil palm biomass residue.

3.1 Empty Fruit Bunch (EFB)

Empty fruit bunches is one of the main solid wastes or by-product of palm oil mill processing.[35] There are small mill plantations in Malaysia with integrated facilities that utilize shredded EFB, together with palm kernel shells and fiber pressed in low pressure boilers for power production purpose.[36,37] However, the mills that utilize EFB are limited since the upfront investment cost for shredding and pressing facilities outweigh the benefits. Therefore, most of the EFBs are simply burned in the incinerators to produce fertilizer.[15] The incineration process will produce emission of excessive "white smoke", and therefore, Malaysian government has introduced regulations to promote alternative management methods for the disposal of the EFB.[38] Understanding the EFB characteristic allow better handling and utilization of resources more efficiently, especially in application of power generation. Biomass characteristics, namely; moisture content, particle size, density, element contents (e.g. C, H, N, S and O), structural constituent contents, ash content and volatile matter contents influence the suitability of EFB as fuel.[39] Studies have been conducted to characterize EFB as feedstock for energy production. From the proximate analysis as shown in Table 2, EFB have relatively high content of moisture. This could incur additional cost for drying. However, EFB have very high volatility and reactivity which were suitable for the production of liquid fuel in the downstream application. The HHV value of EFB is 32MJ/kg which only accounted for 60% of HHV in coal, making it suitable for use as solid fuel to produce syngas. [40]

3.2 Palm Kernel Shell (PKS) and Mesocarp Fiber (MF)

Palm kernel shells and mesocarp fiber are carbonaceous solids materials which are leftovers from palm oil mill processing.[41] Carbonaceous solids contain high volume percentage of carbon element and it can be converted as heat energy source by thermal reaction.[42] In Malaysia, the PKS and MF are currently used as solid fuel feedstock for steam generation and electricity.[43] The steam generated from boiler is used locally for activities in the industry. Meanwhile, the electricity generated is used in-situ and also supplied to nearby residential area. Thus, palm oil mills, in general are self- sufficient in energy generation since excess solid fuel feedstock is available.[16] Table 3 shows that shell and fiber from milling process give significant value of availability after EFB, Frond and trunk. In 2003, Malaysia palm oil mills have generated approximately 300MW of electricity from its palm oil processing by-products mainly from shells and fibers.[36,17] Better characteristic of PKS compared to other residue may become the main factor for its wide usage in industry. Table 4 shows the proximate and ultimate analysis of feed stock reported by Faisal *et al.* (2011) and Pichet *et al.* (2013).[44,45] It is found that PKS has a quite significant content of volatile matter, a moderate proportion of fixed carbon, but rather low content of fuel moisture and ash, thus resulting in high of heating value.

3.3 Oil Palm Frond (OPF)

The chemical composition of OPF consists of 40-50% cellulose, 20-30% hemicellulose and 20-30% lignin as in Table 5.[12,46] Previous studies show that OPF has high potential to be used for gasification.[12] According to FIseha M. *et al*., ultimate and proximate analysis showed that volatile matter content of OPF (83.5%) is comparable to feedstocks such as beach wood and sugarcane bagasse (82.5 and 85.61% respectively), and higher compared to rice husk (68.25%) and coconut husk biomass (70.3%).[14,47–49] The high volatile matter content of OPF implies high reactivity and can be used as a fuel in thermochemical energy conversion such as pyrolysis and gasification for syngas production.[47] OPF have the highest cellulose and lowest lignin and ash contents compared to other oil palm biomass types such as EFB, shells and trunks.[14] Lignin is the most difficult component to be thermally decomposed and accounts for most of the unconverted matter in ash and char due to its high fixed carbon content.[50–52] Therefore, high cellulose composition and low lignin and ash compositions of OPF imply its high potential as gasification fuel.[50]

■4.0 CHARACTERISTIC OF PALM BIOMASS-DERIVED SYNGAS

Syngas produced from the gasification of biomass feedstock is one of the potential sustainable energy with environmentally clean fuel characteristic.[53] Syngas generally has high levels of hydrogen. Research by Nimit *et al.* (2011) using oil palm frond as a feedstock revealed that the hydrogen mole fraction will increase with decreasing reactor temperature and vice versa.[54] The inverse is true for carbon monoxide mole fraction. Samson *et al*. (2013) used OPF as feedstock and reported that concentration of H_2 in syngas increases for oxidation zone temperature range of 500–850°C. At higher temperature, H_2 concentration is slightly drops. [47] In addition, relative to other biomass materials as in Table 6, it was discovered that downdraft gasification of OPF resulted in the highest CO content, the lowest CO2 content, slightly lower H_2 and slightly lower CH_4. Fiseha *et al.* (2012) reported that the oil palm fronds gasification results showed that preheating the gasifying air increased the volumetric percentage of H_2 from 8.47% to 10.53%, CO from 22.87% to 24.94% and CH_4 from 2.02% to 2.03%.[14] Pooya *et al.* (2011) used bubbling bed gasifier to produce syngas from EFB and reported that equivalence ratio of 0.21was the optimum value where the composition of CO, H2, CH4 and CO2 achieved were 16.62%, 5.55%, 4.31% and 19.24%.[55] Zakir *et al.* (2014) used the integrated catalytic adsorption (ICA) steam gasification with fluidize bed to produce high hydrogen content syngas from palm kernel shell where over 80% of hydrogen composition was achieved.[56] Reza *et al.* (2014) also achieved high hydrogen composition from PKS blend with polyethylene waste in a catalytic steam gasification.[57]

Table 2 Properties for Empty Fruit Bunch (EFB)[40]

Proximate analysis (wt% dry basis)		Ultimate analysis (wt.% dry basis and ash free basis)		Lignocellulosic content (wt% dry basis)		HHV (MJ/kg)	
Moisture content		C	45	Cellulose	23.7	Pith	14.0
Pith	82.6	H	6.40	Hemicellulose	21.6	Branch	18.1
Branch	57.5	O	47.3	Lignin	29.2		
Volatile matter	71.2	N	0.25				
Fixed Carbon	18.3	S	1.06				
Ash	7.54						

Table 3 Characteristic of palm oil biomass[36,58]

Biomass component	Quantity available (million tonnes)	Potential energy generation Potential (Mtoe)	Electric generated (GW h)
ref	58	58	36
Empty fruit bunches	17	7.65	46346.15
Palm kernel Shell	5.92	2.84	5792.13
Fiber	9.60	4.37	1578.19
Palm kernel seed	2.11	0.95	
Fronds and trunks	21.10	-	

Table 4 Properties for palm kernel shell (PKS)

Proximate analysis (wt% wet PKS basis)			Ultimate analysis (wt.% dry basis)		
Ref.	44	45	**Ref.**	44	45
Moisture content	11	5.4	C	49.74	48.06
Volatile matter	67.2	71.1	H	5.32	6.38
Fixed carbon	19.7	18.8	O	44.86	34.10
Ash	2.1	4.7	N	0.08	1.27
Holocellulose-cellulose	27.7	38.6	S	0.16	0.09
Alpha-cellulose-hemicellulose	21.6	1.2	Ref.	43	
Lignin	44	39	HHV	16.14MJ/kg	

Table 5 Properties for Oil Palm Frond (OPF)

	Moisture content	**Volatile matter**	**Fixed Carbon**	**Ash**		**Ref.**
Proximate analysis (wt% dry basis)	13.84	82.70	3.22	0.24		12
	16	83.5	15.2	1.3		14
	C	**H**	**O**	**N**	**S**	
Ultimate analysis (wt.% dry basis and ash free basis)	42.76	5.99	50.88	0.39		44
	44.58	4.53	48.80	0.71	0.07	14
	Cellulose	**Hemicellulose**	**Lignin**			
Lignocellulosic content (wt% dry basis)	40.1	30.78	29.50			46
	50.33	23.18	21.7			44
HHV (MJ/kg)	17.28					14
	18.2					59

Table 6 Comparison of syngas composition and heating value for gasification of OPF with other biomass

Biomass type	Dry gas composition (% vol.)				LHV (MJ/Nm^3)	Ref.
	CO	**CO2**	**H_2**	**CH_4**		
OPF	25.3	8.2	9.6	1.2	4.8	47
EFB	16.6	19.2	5.6	4.3	5.9	55
PKS	10.49	0.0	82.1	11.4	13.8	57
Coconut shells	21.3	11.8	13.5	1.5	4.9	47
Hazelnuts shells	19.6	10	12.7	2.0	4.7	
Furniture wood	24.0	14.7	14.7	2.0	5.5	
Woody biomass	20.3	8.3	17.8	1.7	5.3	

■4.0 CONCLUSION

Palm oil industry as the largest producer of biomass in Malaysia can give high potential market to syngas as the main fuel feedstock resources in the future. There are four main type of oil palm biomass which can be utilized as a potential renewable energy; oil palm frond (OPF), empty fruit bunches (EFB), palm kernel shell (PKS) and mesocarp fiber (MF). All of the palm biomass types have high volatile content giving a very good characteristic of heating value. Therefore, all type of palm biomass has potential to be solid fuel resources for syngas production.

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