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Current Status on Hydrogen Production Technology by using Oil Palm Empty Fruit Bunch as a Feedstock in Malaysia

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In Malaysia, the growth of economic is connected to the fossil energy resources which are continued to effect by the growing of energy demand. Hydrogen is an alternative for energy and electricity generation, especially for transportation application and can significantly reduce the carbon monoxide (CO) emission and air pollution. The research on renewable energy especially from biomass such as oil palm empty fruit bunch (OPEFB) can contributes to reduce the concern over the energy insecurity and will help Malaysia in creating a sustainable energy supply. Research on the hydrogen production process by using OPEFB was reported in several papers. However, the review criteria and the best technology for hydrogen production process application are still missing. This paper attempts to develop hydrogen technology database from various types of hydrogen production process of OPEFB. It can be used to determine the most feasible and promising route to be applied. This study is also significant in helping the industry to see the differences of various design alternatives and make process design decisions on them.

1. Introduction

Research on renewable energy from biomass has become a common interest between researchers in parallel to the increase utilisation of renewable energy. The production of renewable energy from biomass can reduce the dependency toward fossil fuel as well as to combat environmental problems such as global warming, acid rain, and others (Ni et al., 2006). Hydrogen can be made directly from fossil fuels or biomass. Most hydrogen production is from steam reforming natural gas. But natural gas is already a good fuel and one that is rapidly becoming scarcer and more expensive. It is also a fossil fuel, so the carbon dioxide released in the reformation process adds to the greenhouse effect. The study on hydrogen production from biomass such as oil palm empty fruit bunch (OPEFB) is needed to reduce the fossil fuel dependency. Hydrogen has great potential to provide energy to all sectors of the economy, including transportation, buildings and industry and can further lead to a low carbon energy system sometimes called the Hydrogen Economy (Zhang et al., 2016). Hydrogen has very high energy for its weight, but very low energy for its volume, so new technology is needed to produce, store and transport it. Currently, over 50 million tons of hydrogen is produced worldwide annually. An estimated 95 % or more is from fossil fuels (Zhang et al., 2016). Oil palm (*Elaeis guineensis*) is a tropical plant which is originally come from Africa. It was first introduced in Malaysia as an ornamental plant in 1870. The planted area increase over the year which is from 1.5 million hectares in 1985 to 4.3 million hectares in 2007 and 4.917 hectares in 2011 (MPOB, 2011). Malaysia has the important role in fulfilling the growing global need for oils and fat sustainability since Malaysia currently accounts for around 39 % of world palm oil production and 44 % of world exports (MPOB, 2011). Oil palm tree has become the most important agricultural crop in Malaysia and has become the key to the national economic expansion (Chang, 2014). Currently there is a strong global demand for palm oil and Malaysia is the second largest producer of palm oil in the world (Gan and Li, 2014). According to (MATRADE, 2014), palm oil represent the fifth largest export of Malaysia in 2014 which is RM 46.95 billion (6.1 %) which contribute towards Malaysian Gross National Income (GNI). The main problem in the oil palm tree cultivation and its related industries is its substantial amount of biomass waste. The wastes such as empty fruit bunches (EFB), palm kernel shell (PKS), mesocarp fiber (MF),

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palm oil mill effluent (POME), oil palm trunks (OPT), oil palm leaves (OPL) and oil palm fronds (OPF) which are generated from oil palm fruits harvesting, palm oil processing or during oil palm trees replantation (Awalludin et al., 2015). The wastes are mostly burnt in open air or dumped which generate pollutants including dust, acid rain gases such as NO_x and SO_x and large amount of methane which is a more potent greenhouse gas than CO_2. In developed countries, there is a growing trend towards the use of biomass based energies. These technologies which use waste or plant matter to produce energy, emit less greenhouse gas than fossil fuels and are cost wise competitive with conventional energy resources.In Malaysia, the used of biomass such as EFB is still on the research phase. This study may give the brief insight towards application of such technology for hydrogen production from EFB as an alternative for energy production.

The oil palm empty fruit bunches (OPEFB) is the solid residue that is produce in the highest amount from the fresh fruit bunches of oil palm. According to Baharuddin et al. (2009), 368 of palm mills in Malaysia will produce 53 % of palm empty fruit bunches, 32 % of palm mesocarp fiber and 15 % palm kernel shell. Huge amount of OPEFB being produce every day since oil palm is the dominant agricultural crop and more than 3.88 million hectares of land in Malaysia are under palm cultivation (Lahijani and Zainal, 2011). OPEFB is the empty husks left over after the oil extraction from palm fruit. Earlier, before the new technology for processing the OPEFB into source of energy being discovered, the OPEFB is converting to compost. Those crude palm oil mills having their own estate will gather the OPEFB, expose to air to let it turn black and start fermentation. New application of OPEFB make use of the fiber nature of the OPEFB. There are also researches about pressed and shredded OPEFB to obtain fiber as fuel for biomass boiler (Awalludin et al., 2015). Many researches have been done in relation to thermochemical process for hydrogen production from OPEFB. However, the ultimate approaches of hydrogen production from OPEFB is still in research. This research may assist in providing a review of the hydrogen production technology from OPEFB toward the aims of Malaysia in the development of renewable energy. Energy development is a significant part of sustainable development and is crucial to the success of the industrialisation process. Malaysian economic growth and competitiveness and its position in the global economy are therefore will greatly influenced by energy development.

2. Renewable energy in Malaysia

It is expected that in 2020, at least 78 Mt of palm oil will be in demand by consumers worldwide. As a result, higher amount of OPEFB will be produced, and yet there is still no effective ways to optimise the utilisation of these abundant and valuable source of wastes (Gan and Li, 2014). Research focusing on the hydrogen production by using OPEFB as a feedstock can enhance the development of the renewable energy plant in Malaysia and support Malaysia Small Renewable Energy Power Plant Program which aims to reduce 40 % of greenhouse gases emissions by 2020 (Lange and Pellegrini, 2013). According to Daud (2006), hydrogen energy roadmap for Malaysia has been divided into 3 time period which are the short term (2005 - 2010), the medium term (2011 - 2029) and the long term (2030 onwards). Currently, real condition of hydrogen development in Malaysia is still behind the propose schedule. According to the hydrogen energy roadmap, in 2015, it should be in the process of enhancement of hydrogen technology and to become global supplier of hydrogen based fuel in 2025. The hydrogen production technology from OPEFB is still in the preliminary stage and research in process design for hydrogen production is still missing. It is expected from 2030 onwards (long term plan), the introduction and utilisation of renewable hydrogen energy should be established. In anticipation of hydrogen economy and to support the aim to make hydrogen as an attractive and competitive energy source, projects on the centralised hydrogen facilities, process design and feasibility need to be conducted (Daud, 2006). The source of energy can be divided into two sources which are primary and secondary. Hydrogen is a secondary source of energy because it is an energy carrier not an energy resource and hydrogen need to be produced first. In order to avoid the dependency on fossil hydrocarbon, alternative process for hydrogen generation that is economical, environmentally friendly, and competitive need to be developed.

Salleh et al. (2010) stated that by 2100, Malaysia will face energy scarcity if there is no alternative sources of energy is implemented since the current oil and gas reserves for Malaysia will last for 16 years (oil) and 32 years (gas). Energy development is a significant part of sustainable development and is crucial to the success of the industrialisation process. Malaysian economic growth and competitiveness and its position in the global economy will greatly influenced by energy development (Gan and Li, 2014). The production of hydrogen from biomass as an alternative for fossil fuel will be in high demand in the future due to many applications of hydrogen. Numerous works have been done in a fundamental research of hydrogen production from OPEFB as a feedstock due to it substantial amount of biomass waste from palm oil industries (Sivasangar et al., 2015) and it significant potential and benefit as a renewable energy (Nyakuma et al., 2014). According to Awalludin et al. (2015), further research should be carried out to ensure the use of oil palm wastes is more efficient and reliable.

3. Hydrogen production process technologies

Hydrogen can store and deliver usable energy, but it does not typically exist by itself in nature and must be produced from compounds that contain it. Figure 1 summarised an example of different kind of sources for hydrogen generation which can come from fossil hydrocarbon, biomass, water, synthetic fuel and others. Nowadays, fossil fuel is the main source of hydrogen generation. It is being produce on a large industrial scale through steam reforming. However, fossil fuel resources will be exhausted soon and the usage of fossil as a main energy produce large amount of CO_2 and later will increase the concentration of greenhouse gases concentration. Hydrogen generation from biomass such as OPEFB, wood chips, rice husk and so on can be a good alternative as an energy source since huge amount of biomass residue being produce each year and biomass waste can be considered as an eco-friendly with minimal environmental impact. This readily available biomass source stored incredible energy that can be harvested through emerging technologies such as membrane reactor, plasma reforming and so on which can assist to solve current problems such as energy crisis problem, waste management and environmental problem.

There are few researches on technology to produce hydrogen from biomass such as biological and thermochemical processes. Biological process can be further divided into three processes which are dark fermentation, photo fermentation which required the light or also called as light dependent and two stage processes combining dark fermentation with either photo fermentation or bio-electrogenesis in microbial fuel cell (Urbaniec and Bakker, 2015).

There are four major thermochemical conversion process which are liquefaction, pyrolysis, combustion and gasification (Basu, 2010). From Table 1, it shows that pyrolysis and gasification is the most common process being used for hydrogen generation since it used high temperature and can produce significant amount of hydrogen.

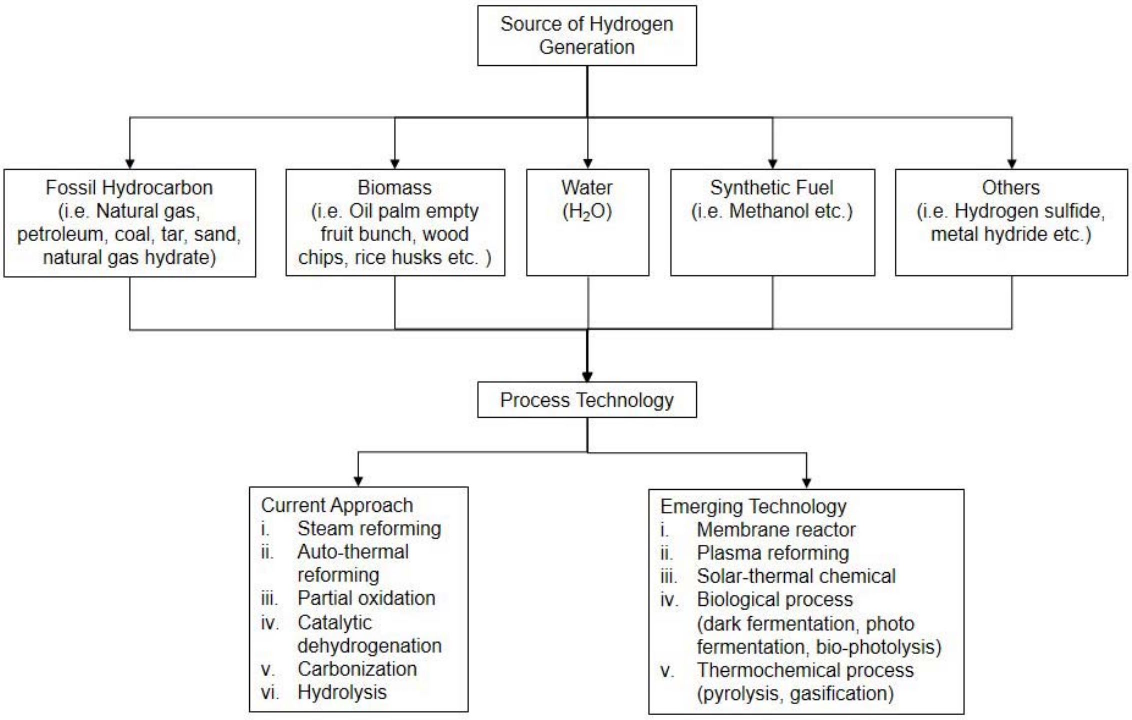

Figure 1: Sources and technologies available for hydrogen generation

In this paper, data of hydrogen production from OPEFB were collected in regards to chemical involved, reaction, temperature and percentage of hydrogen yield. Data mining process was used in this research. Data mining is a process of analysis that is used to reveal interesting pattern, association or relationship between various elements from a large amount of data stored in database of information resources. Data mining comprises of different steps and techniques such as data cleaning, data integration, data selection, data pre-processing, data transformation, pattern evaluation and knowledge presentation.

Table 1: Analysis of hydrogen production technology from OPEFB

Technology	Ultimate Analysis (wt%)					Proximate Analysis (wt%)				Feeds-tock size (µm)	Upper tempe-rature (°C)	Hydro-gen yield (%)
	C	H	N	S	O	Moist-ure	Vo-lati-les	Ash	Fixed carb-on			
Gasification (Fluidised bed reactor) (Lahijani and Zainal, 2011)	43.5	5.7	1.2	0.7	48.9	7.8	79.3	4.5	8.36	-	1,050	12.4
Fast pyrolysis (Fluidised bed reactor) (Sulaiman and Abdullah, 2011)	49.1	6.5	0.7	< 0.1	38.3	7.95	83.9	5.4	10.78	250-355	450	9.61
Gasification (Fluidised bed reactor) (Mohammed et al., 2011b)	46.6	6.5	1.2	0.04	45.7	5.18	82.6	3.5	8.79	300	1,000	38.02
Dark Fermentation (Chong et al., 2013)	-	-	-	-	-	-	-	-	-	-	-	58 (pH 5.5)
Gasification (Entrained-flow gasifier) (Ogi et al., 2013)	46.3	5.9	0.5	-	44.6	-	-	2.7	-	-	900	67 - 75 (H_2 + CO)
Gasification (Circulating fluidised-bed (CFB)) (Hussain et al., 2006)	49.5	5.9	0.5	0.1	40.6	6.8	77.4	3.3	19.3	5,000	709	5
Pyrolysis (fixed bed reactor) (Yang et al., 2006)	48.8	7.3	0	0.68	40.2	8.75	79.7	3.0	8.65	< 1,000	900	36.36
Gasification (Fluidised Bed Reactor) (Salleh et al., 2010)	61.5	10.5	2.0	-	26.0	5.4	25.4	-	54.05	500	850	27.97
Gasification (Fluidised bed reactor) (Mohammed et al., 2011a)	53.1	4.4	0.4	0.68	41.5	3.3	83.9	7.1	5.68	< 1,000	1,000	38.02

Table 1 shows the data analysis of various types of hydrogen production technology from OPEFB. Among the technologies that have been analysed were dark fermentation process and gasification as well as pyrolysis by using a different kind of reactors. Currently, there are very limited studies done in hydrogen production process by using OPEFB and sometime the result of analysis from the open literature is not completed yet. In this study, only few processes can be analysed after data cleaning and selection process. Based on the result, the ultimate analysis shows that OPEFB is environmentally friendly with very little and almost no trace amounts of nitrogen, sulphur and mineral matter. Result from proximate analysis from a several studies shows that OPEFB consist of low concentration of moisture content. This condition makes the OPEFB as a good source for hydrogen generation since according to Kumar et al. (2014), gasification efficiency will increase with decrease concentration of moisture content. From the analysis, feedstock size and upper temperature play an important role in the hydrogen production. Increase in feedstock particle size causes greater temperature gradient inside the particle so that at a given time, the core temperature is lower that the surfaces which possibly give rise to the char and liquid yield and reduce in the gases concentration. The percentage of hydrogen yield is increase as the temperature increase based on result in Table 1. It is also shows that the gasification process of OPEFB by using fluidised bed reactor is favourable and produce high amount of hydrogen concentration which is around 38.02 %.

4. Conclusions

In this study, the current status for hydrogen production technology from OPEFB was developed base on available data from open literature. It is necessary to identify the best process condition to assist the development of commercial hydrogen production plant from OPEFB. Since currently, in Malaysia, there is no commercial gasification plant employing biomass has been registered (Lahijani and Zainal, 2011). In a conclusion, OPEFB can be a good source for alternative energy in a future due to its abundant amount being produce every year with no specific used and also because of it properties such as environmentally friendly with low amount of sulphur, nitrogen as well as mineral matter, high hydrogen content and low moisture content. Furthermore, several technologies have been studied to investigate the most effective process to produce hydrogen from OPEFB, and gasification process by using fluidised bed reactor can be considered as the most effective process to be used for the development of commercial hydrogen production plant from OPEFB due to its excellent mixing, efficient heat temperature control and tolerance for fuels. In a future, study on its process safety and hazards need to be done in order to reduce the risk of the hydrogen production plant from OPEFB since hydrogen releases can result in fire and explosion due to mechanical failure, corrosion, human error etc.

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Reference

Awalludin M.F., Sulaiman O., Hashim R., Wan Nadhari W.N.A., 2015, An Overview of the Oil Palm Industry in Malaysia and Its Waste Utilization through Thermochemical Conversion, Specifically Via Liquefaction, Renewable and Sustainable Energy Reviews 50, 1469-1484.

Baharuddin A.S., Wakisaka M., Shirai Y., Abd-Aziz S., Abdul Rahman N.A., Hassan M.A., 2009, Co-Composting of Empty Fruit Bunches and Partially Treated Palm Oil Mill Effluents in Pilot Scale, International Journal of Agricultural Research 4 (2), 69-78.

Basu P., 2010, Biomass Gasification and Pyrolysis: Practical Design and Theory, Academic press, Waltham, MA, U.S.A.

Chang S.H., 2014, An Overview of Empty Fruit Bunch from Oil Palm as Feedstock for Bio-Oil Production, Biomass and Bioenergy 62, 174-181.

Chong P.S., Jahim J.M., Harun S., Lim S.S., Mutalib S.A., Hassan O., Mohd Nor M.T., 2013, Enhancement of Batch Biohydrogen Production from Prehydrolysate of Acid Treated Oil Palm Empty Fruit Bunch, International Journal of Hydrogen Energy 38 (22), 9592-9599.

Daud W.R.W., 2006, Hydrogen Economy: Perspective from Malaysia, International seminar on the hydrogen economy for sustainable development, 28 -29 September 2006, Reykjavik, Iceland.

Gan P.Y., Li Z.D., 2014, Econometric Study on Malaysia′ S Palm Oil Position in the World Market to 2035, Renewable and Sustainable Energy Reviews 39, 740-747.

Hussain A., Ani F.N., Darus A.N., Mokhtar H., Azam S., Mustafa A., 2006, Thermochemical Behaviour of Empty Fruit Bunches and Oil Palm Shell Waste in a Circulating Fluidized-Bed Combustor (CFBC), Journal of Oil Palm Research 18, 210-218.

Kumar H., Baredar P., Agrawal P., Soni S.C., 2014, Effect of Moisture Content on Gasification Efficiency in Down Draft Gasifier, International Journal of Scientific Engineering and Technology 3 (4), 411-413.

Lahijani P., Zainal Z.A., 2011, Gasification of Palm Empty Fruit Bunch in a Bubbling Fluidized Bed: A Performance and Agglomeration Study, Bioresource Technology, 102 (2), 2068-2076.

Lange S., Pellegrini L.A., 2013, Economic Analysis of a Combined Production Of hydrogen-Energy from Empty Fruit Bunches, Biomass and Bioenergy, 59, 520-531.

Matrade (Malaysia External Trade Development Corporation), 2014, Top 10 Major Export Products <www.matrade.gov.my/en/malaysia-exporters-section/33-trade-statistics/3184-top-10-major-export-products-2014> Accessed 06.10.2015.

Mohammed M.A.A., Salmiaton A., Wan Azlina W.A.K.G., Mohamad Amran M.S., 2011a, Gasification of Empty Fruit Bunch for Hydrogen Rich Fuel Gas Production, Journal of Applied Sciences 13 (11), 2416-2420.

Mohammed M.A.A., Salmiaton A., Wan Azlina W.A.K.G., Mohamad Amran M.S., Fakhru'l-Razi A., 2011b, Air Gasification of Empty Fruit Bunch for Hydrogen-Rich Gas Production in a Fluidized-Bed Reactor, Energy Conversion and Management, 52 (2), 1555-1561.

MPOB (Malaysian Palm Oil Board), 2011, Oil Palm in Malaysia <www.palmoilworld.org/about_malaysian-industry.html> Accessed 18.09.2015.

Ni M., Leung D.Y.C., Leung M.K.H., Sumathy K., 2006, An Overview of Hydrogen Production from Biomass, Fuel processing technology 87, 461-472.

Nyakuma B.B., Johari A., Ahmad A., Tun Abdullah T.A., 2014, Comparative Analysis of the Calorific Fuel Properties of Empty Fruit Bunch Fiber and Briquette, Energy Procedia 52, 466-473.

Ogi T., Nakanishi M., Fukuda Y., Matsumoto K., 2013, Gasification of Oil Palm Residues (Empty Fruit Bunch) in an Entrained-Flow Gasifier, Fuel 104, 28-35.

Salleh M.A.M., Kisiki N.H., Yusuf H.M., Wan Ab Karim Ghani W.A., 2010, Gasification of Biochar from Empty Fruit Bunch in a Fluidized Bed Reactor, Energies 3 (7), 1344-1352.

Sivasangar S., Zainal Z., Salmiaton A., Taufiq-Yap Y.H., 2015, Supercritical Water Gasification of Empty Fruit Bunches from Oil Palm for Hydrogen Production, Fuel 143, 563-569.

Sulaiman F., Abdullah N., 2011, Optimum Conditions for Maximising Pyrolysis Liquids of Oil Palm Empty Fruit Bunches, Energy 36 (5), 2352-2359.

Urbaniec K., Bakker R.R., 2015, Biomass Residues as Raw Material for Dark Hydrogen Fermentation – A Review, International Journal of Hydrogen Energy 40, 3648-3658.

Yang H., Yan R., Chen H., Lee D.H., Liang D.T., Zheng C., 2006, Pyrolysis of Palm Oil Wastes for Enhanced Production of Hydrogen Rich Gases, Fuel Processing Technology 87, 935-942.

Zhang F., Zhao P., Niu M., Maddy J., 2016, The Survey of Key Technologies in Hydrogen Energy Storage, International Journal of Hydrogen Energy 41 (33), 14535-14552.