International Conference on Mechanical Engineering Research (ICMER2013), 1-3 July 2013
Bukit Gambang Resort City, Kuantan, Pahang, Malaysia
Organized by Faculty of Mechanical Engineering, Universiti Malaysia Pahang
Paper ID: P323

AN OVERVIEW OF PALM, JATROPHA & ALGAE AS A POTENTIAL BIODIESEL FEEDSTOCK IN MALAYSIA

Syarifah Yunus[1*], N. R. Abdullah[1], R. Mamat[2*], A. A. Rashid[1]

[1]Faculty of Mechanical Engineering, Universiti Teknologi Mara,
40450 Shah Alam, Selangor, Malaysia
*Email: sya_mechys@yahoo.co.uk
Phone: +60176696521
[2]Faculty of Mechanical Engineering, University Malaysia Pahang
26600 Pekan, Pahang, Malaysia
*Email: rizalman.mamat@yahoo.com

ABSTRACT

The high demand to replace the petroleum fuel makes renewable and sustainable sources such as Palm oil, Jatropha oil and Algae as main focus feedstock for biodiesel production in Malaysia. There are many studies conducted on Palm oil and Jatropha oil, however, the use of Algae as an alternative fuel is still in its infancy. Malaysia already implemented B5 based Palm oil as a feedstock and this biodiesel has been proven safe and can be used without any engine modification. The use of biodiesel produced from these feedstock will also developed domestic economic and provide job opportunities especially in the rural area. In addition, biodiesel has many advantages especially when dealing with the emissions produce as compared to petroleum fuel such as; it can reduce unwanted gases and particulate matter harmful to the atmosphere and mankind. Thus, this paper gathered and examines the most prominent engine emission produced from Palm oil and Jatropha feedstock and also to observe the potential of Algae to be one of the sources of alternative fuel in Malaysia.

***Keywords*:** Palm oil; Jatropha; Algae; biodiesel; emission

INTRODUCTION

Alternative fuels for diesel engine, boilers and other combustion equipment becoming increasingly important due to the depletion of petroleum reserves in the near future. The dependence and the consumption of petroleum products is increasing day-by-day and it is resulting in higher prices of petroleum fuel. The global primary petroleum fuel consumption has grown up from 6630 million tons in 1980 up to 12,002.4 million tons (it is almost double) in 2010 (Mofijur et al., 2012; Ong et. al., 2011). Malaysia is also one of the countries that suffered from this crisis, as according to British petroleum statics, oil production in Malaysia in 2001 has decrease from 32.9 million tons to 32.1 million tons in 2010. However, the corresponding consumption of oil has increased from 22 million tons in 2001 to 25.3 million tons in 2010 (Mofijur et al., 2012).

The emission emitted from the petroleum fuel may cause various negative impacts on global climate of greenhouse gases and also lead to acid rain and air pollution. It is predicted that if the average global temperature increases by more than 2^oC, more than million species could extinct and hundreds of millions people could lose their lives (Ahmad et al., 2011; Atabani et al., 2012). Living people may also suffer from various diseases such as lung cancer, breathing difficulties, poisoning and skin cancer etc. This concern led to find the alternative fuel to overcome these problems and Malaysia is no exception.

Biofuels from various biomasses seems to be a realistic alternative renewable fuel to resolve twin crisis of petroleum depletion and environmental degradation. The implementation of biomass energy will contribute to sustainable development in various fields of environmental, social and economic. Biomass feedstocks used for biodiesel production include Algae, animal fats and vegetable oils like Palm, Jatropha, rapeseed, sunflower etc. Brazil and US for example are promoting ethanol as a potential biofuel derived from sugar cane and corn, and Asian countries like Malaysia, Indonesia and India have been promoting Palm oil and Jatropha as biodiesel throughout widely (Abdullah et al., 2009; Mekhilef et al., 2011; Ong et al., 2012; Sahoo & Das, 2009; Yusuf et al., 2011).

There are so many advantages and disadvantages of using biodiesel as compared to diesel fuel. Figure 1 show some of the literature gathered by past researcher (Atabani et al., 2012).

Advantages
Biodiesel has 10-11% of oxygen; this makes biodiesel a fuel with high combustion characteristics.
Biodiesel reduces net carbon-dioxide emissions by 78% on a lifecycle basis when compared to conventional diesel fuel and reduces smoke due to free soot.
Biodiesel has superior better lubricity properties. This improves lubrication in fuel pumps and injector units, which decreases engine wear, tear and increases engine efficiency.
Biodiesel has higher cetane number (about 60-65 depending on the vegetable oil) than petroleum diesel (53) which reduces ignition delay.
Biodiesel may not require engine modification up to B20. However, higher blends may need some minor modification.
Production can be raised easily and is less time consuming.
Disadvantages
Biodiesel has 12% lower energy content than diesel; leads to increase fuel consumption of about 2-10%.
Biodiesel causes excessive carbon deposition and gum formation (polymerization) in engine and oils get contaminate and suffer from flow problem.
Biodiesel has higher cloud point and pour point, higher nitrogen oxide emissions, lower volatilities that cause formation of deposits in engine due to the incomplete combustion characteristics.
Transesterification process is expensive (cost of fuel increases), these oil require expensive fatty acid separation or use of less effective (or expensive acid catalyst).
Use of biodiesel in internal combustion engine may lead to engine durability problems including injector cocking, filter plugging and piston ring sticking, etc.
Lower engine speed and power, high price, high engine wear, engine compatibility.

Figure 1. Advantages and disadvantages of biodiesel

Malaysia had launched the National Biofuel Policy to encourage more sources from renewable energy (*Ministry of plantation industries and commodities, Malaysia*). The policy was eventually launched in March 2006 and is underpinned by five strategic thrusts, with short-term, medium-term and long-term implementation periods. Figure 2 below show the summary of the National Biofuel Policy (Chin, 2011).

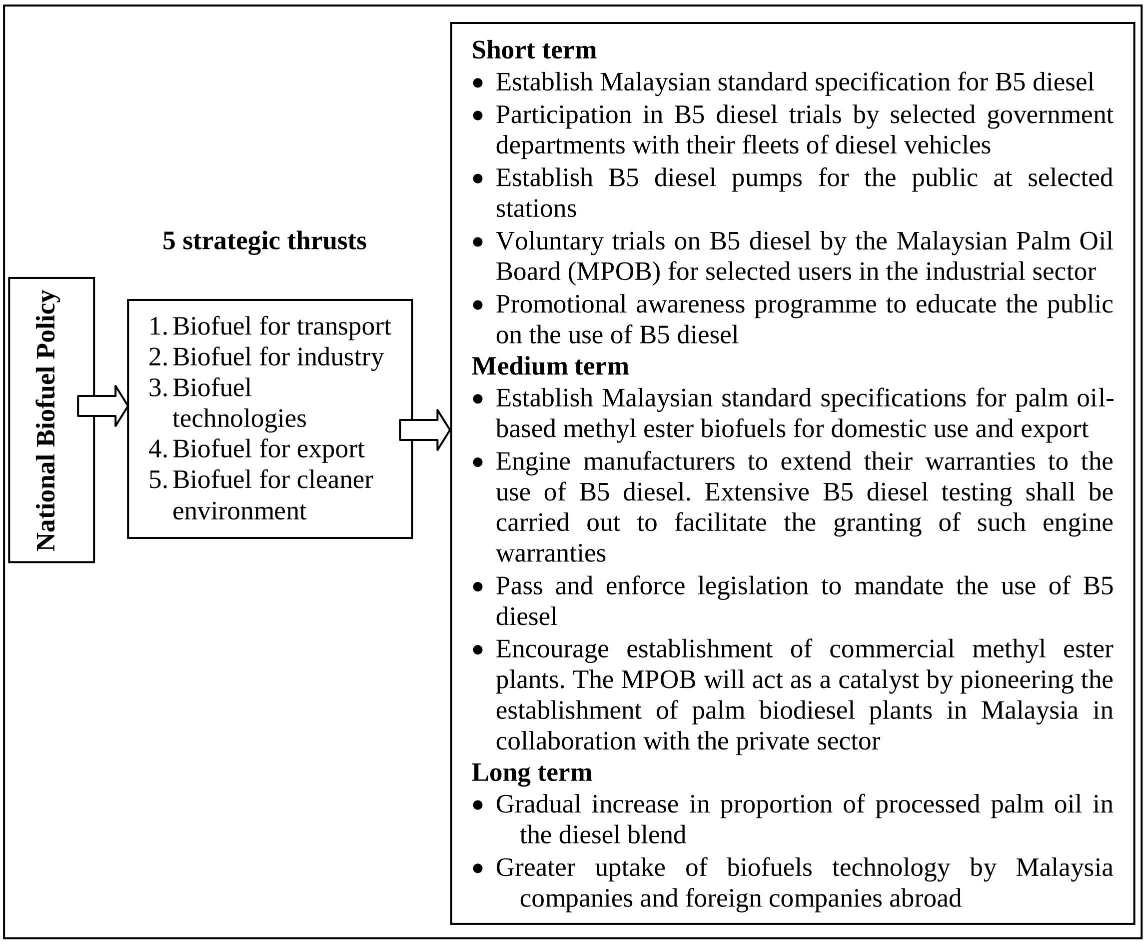

Figure 2. Implementation of National Biofuel Policy in Malaysia

Malaysia has introduced a 5 percent biodiesel blended composition which is 5 percent consist of Palm oil methyl ester (POME) and known as B5 since mid-year 2011. Currently, extensive research also has been conducted in Malaysia to promote the usage of Jatropha and Algae biodiesel as they are easily obtained (Ahmad et al., 2011; Akbar et al., 2009; Azhari et al., 2008; Choudry et al., 2011). Compatible with climate change in Malaysia make Jatropha a promising alternative fuel. Apart from that, Algae also has attracted many researchers as it is easy to be found especially in Sabah and Sarawak. However, the use of Algae as an alternative fuel is still in its infancy (Ahmad et al., 2011).

This paper gathered and discusses the work carried out by past researcher on vegetable oil - Palm, and non-edible oil - Jatropha curcas, and also potential of Algae to be one of the sources of alternative fuel. The engine performances from Palm and Jatropha feedstock are reported comparable as compared to petroleum fuel (Baitiang et al., 2008; Kamei et al., 2010; Mamat et al., 2012). However, the emission results indicate variation in emission with the use of these biodiesel (Hoekman & Robbins, 2012; Sahoo et al., 2009; Tan et al., 2012; Yusop et al., 2012). Thus, effort has been made in this study to review the most prominent engine emissions produced from Palm and Jatropha feedstock.

POTENTIAL OF PALM OIL AS A FEEDSTOCK FOR BIODIESEL SOURCE

Malaysia is currently implementing biodiesel known as B5 (5% Palm oil methyl ester and 95% diesel fuel) based Palm oil as a feedstock. The usage of this B5 in diesel engine is safe and has been used without any engine modification. The performance of biodiesel is also comparable to diesel engine reported by other researchers (Bora et al., 2012; Sahoo & Das, 2009; Sahoo et al., 2009). Some types of emissions also reduced when used this Palm oil biodiesel (Atabani et al., 2012; Liaquat et al., 2010; Ong et al., 2011).

Malaysia is listed as the largest world exporter of Palm oil and the second largest of Palm oil producer after Indonesia. Malaysia as 2010, the area of oil Palm plantation was 4.85 million hectares covering 14% of the total land area in Malaysia (Chin, 2011). Currently, Malaysia encourages private companies to further intensify in this project, providing adequate subsidies to the parties involved and increase programs to encourage farmers to nurture the growth of the biodiesel industry. This could indirectly provide job opportunities, especially in rural areas.

POTENTIAL OF JATROPHA OIL AS A FEEDSTOCK FOR BIODIESEL SOURCE

In the future, Jatropha can be one of the sources biodiesel productions in Malaysia. Jatropha oil has been found promising for biodiesel production due to the attracting characteristics and it is claimed not to compete with food, not to compete with agriculture land and nature. The biodiesel produced from this feedstock also reduce the danger of emissions compared with the petroleum fuel. This biodiesel also has a comparable cetane number and calorific value with petroleum diesel and it can be used in the diesel engine without requiring any major modifications in the mechanical system of the engines (Baitiang et al., 2008; Kamei et al., 2010; Sahoo & Das, 2009; Sahoo et al., 2009).

The advantages of climate suitability and availability of land in Malaysia has made Malaysia took the opportunity to explore and expand Jatropha production. It is reported that a total of 1712 hectares of land has been identified as a start of primary production of Jatropha and expected to increase to 57,601 hectares by 2015 (Kalam et al., 2012). A few international leading oil company are also interested to investing and develop the Jatropha projects in Malaysia (Kalam et al., 2012; Mofijur et al., 2012).

POTENTIAL OF ALGAE AS A FEEDSTOCK FOR BIODIESEL SOURCE

Algae as an alternative fuel are still in its infancy in Malaysia. Currently, extensive studies have been carried out to identify the most suitable Algae species to be a source of alternative fuel. Much effort also has been conducted in order to produce biodiesel from this feedstock mainly in Sabah and Sarawak area.

Algae is a promising source of alternative fuel as it will not compromise with food, fodder and other products derived from crops (Ahmad et al., 2011). Algae also provide a reduction in greenhouse gases because it absorbs or utilize carbon dioxide as it grows ("Algae-based Biofuel: Pros And Cons,"). It can grow quickly at a large scale and potential to generate up to 50 times more than the amount of other crops ("Economic Benefits of Algae,"). Due to these advantages, Algae has attracted the attention of many researchers to make one of the alternative fuels to replace the petroleum fuels.

EMISSIONS OF BIODIESEL

The diesel and also biodiesel fuelled engine emits the unwanted gases in the atmosphere that can be hazardous to mankind. There are two types of emissions that have been produced by this diesel engine. One type is known as regulated emissions as it is regulated by the government of many countries and another one is known as unregulated emissions as it is not-regulated by the government. The regulated emissions examples are carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxide (NOx), unburned hydrocarbon (HC) and smoke opacity, whereas, the unregulated emissions examples are formaldehyde, acetaldehyde, acetone and toluene (Tan et al., 2012). However, this study is only limited to observe the most prominent regulated emissions pollutant form Palm and Jatropha feedstock.

PALM OIL’S EMISSIONS

T.H. Lim et al. (2002) conducted the study of CO and NO emissions of a diesel engine operated on 60^oC heated crude Palm oil (CPO). It was observed that higher CO and NO emissions produced by 2.8% and 25.7% respectively as compared to diesel fuel. This is due to the chemical reaction at the core of fuel spray of CPO which produces heavy compounds that are less volatile. These heavy compounds resulted in local-rich mixtures that cause more CO to produce. Higher pressure in the engine cylinder during CPO combustion lead to the higher temperature that caused more NO formation resulted in increasing of NO emission produced.

On the other hand, J. Narkpakdee et al. (2012) evaluated the emission characteristics of diesel-crude Palm oil-water emulsion blend in a small diesel engine. The result shows that the emission parameters such as CO, NOx and black smoke were significantly lower than diesel fuel. This is due to the emulsified water content (that is up to 10%) in the blend biodiesel which reduces the viscosity and heating value.

A.M. Liaquat et al. (2010) carried out experimental study on exhaust emissions of a diesel engine using Palm diesel blend with diesel fuel. The experiment was conducted at constant speed of 2000 rpm at varied load conditions between 5 Nm to 17.5 Nm with intervals of 2.5 Nm. The result shows that the CO emission of the Palm diesel blends produced was less than the diesel fuel at all loads. However, CO_2 and NOx emissions produced were higher as compared to diesel fuel at the higher load applied. This is indication of complete combustion of more amount of CO_2 produced by this Palm diesel fuel in exhaust emissions and the increasing of NOx is caused by its higher heating value and also the increasing of combustion chamber temperatures.

The influence of Palm oil biodiesel on the chemical composition of the particulate matter emissions produced in an automotive diesel engine operated with Palm biodiesel and its blends with diesel fuel were carried out by Maurin Salamanca et al. (2012). The study shows that the particulate matter emissions and smoke opacity amount decreases in a non-linear way as the proportion of Palm biodiesel increases as compared to diesel fuel. This reduction is caused by the chemical nature of the fuels as biodiesel has high level of oxygen and the absence of aromatics molecules it its composition that lead to reduction of particle nucleation and increase the oxidation rate.

JATROPHA OIL'S EMISSIONS

Bhupendra Singa Chauhan et al. (2010) studied the effects of fuel inlet temperature (FIT) on engine emissions using a dual fuel engine test rig with tube heat exchanger (with exhaust bypass arrangement) using Jatropha oil as a fuel. The results show lower NOx emission produced by Jatropha oil as compared to petroleum fuel; nevertheless, increasing FIT caused the increasing of NOx emission. Other gases produced by Jatropha oil resulted in higher CO, HC and CO_2 than petroleum fuel. However, preheated Jatropha oil, the emissions of CO, HC and smoke opacity were reduced but it is slightly increased for CO_2 emission. The higher amount of CO_2 produce from the diesel engine is an indication of the complete combustion of the fuel (Liaquat et al., 2010). S. Jindal et al. (2010) investigated the emissions of Jatropha methyl ester on DI-CI engine. The results show that the HC and NOx emission produced were less than petroleum diesel. The reduction of HC emission is caused by the higher oxygen content present in the biodiesel that leading to more complete combustion. This is also due to higher cetane number that reducing combustion delay and advancing the injection and combustion timing (Lapuerta et al., 2008; Ong et al., 2011).

Iman K. Reksowardo et al. (2007) found that the emissions of CO, CO_2 and HC of Jatropha oil were lower as compared to petroleum diesel and slightly increase of NOx emission. The experiment was conducted on a Direct Injection (DI) diesel engine. The result from this study was with the agreement of other studies, and the slightly increasing of NOx is caused by the oxygenated in biodiesel fuel (Kamei et al., 2010; Tan et al., 2012). The increasing of NOx occurred especially when the engine load increases, as more fuel is injected and burned in the engine cylinder which causes the gas to a higher temperature and resulted in a more NOx formation in the engine cylinders and produce higher NOx emissions from the engine (Pandey et al., 2012).

On the other hand, T. Elango and T. Senthilkumar (2011) evaluated the emissions characteristics of Jatropha oil blends in a CI engine. The results show that all the Jatropha oil blends emitted less CO, CO_2 and HC than the diesel fuel. However, the smoke opacity was increased with increasing proportion of Jatropha oil in the blends as compared to diesel fuel. The increasing of smoke opacity amount is caused by the poor atomization and combustion due to the higher viscosity of the blends (Elango & Senthilkumar, 2011).

Table 1 below shows related research findings of emissions from Palm oil and Jatropha oil.

Table 1. Summary emissions produce from Palm oil and Jatropha oil

Emissions	Palm oil	Jatropha oil
CO increase	Preheated: (Lim et al., 2002)	
CO decrease	Water-emulsion: (Narkpakdee et al., 2012)	Blended: (Elango & Senthilkumar, 2011), (Reksowardoj et al., 2007) Preheated: (Chauhan et al., 2010)
CO_2 increase	Blended: (Liaquat et al., 2010)	Preheated: (Chauhan et al., 2010)
CO_2 decrease		Blended: (Elango & Senthilkumar, 2011) (Reksowardoj et al., 2007)
NO increase	Preheated: (Lim et al., 2002)	
NOx increase	Preheated: (Lim et al., 2002)	Blended: (Reksowardoj et al., 2007)
NOx decrease	Water-emulsion: (Narkpakdee et al., 2012)	
HC decrease		Blended: (Elango & Senthilkumar, 2011), (Reksowardoj et al., 2007) Preheated: (Chauhan et al., 2010)
Smoke opacity increase		Blended: (Elango & Senthilkumar, 2011)
Smoke opacity decrease	Water-emulsion: (Narkpakdee et al., 2012) Blended: (Salamanca et al., 2012)	Preheated: (Chauhan et al., 2010)
Particulate matter decrease	Blended: (Salamanca et al., 2012)	

CONCLUSIONS

This paper has presented a potential of biodiesel feedstock from Jatropha, Palm and Algae. The implementation of B5 based Palm oil as a feedstock in Malaysia had proven that this biodiesel blend can be safely used without any major modification of diesel engine. Currently, due to the climate suitability and land availability in Malaysia make Jatropha as a promising alternative to replace petroleum fuel. The advantages of Algae also attracted attention from many researchers and it is another promising source of alternative fuel. However, the current stage of Algae biodiesel is still in its infancy. Therefore, further research and studies on Algae biodiesel are needed before it can prove to be used in a diesel engine.

This paper also reviews some emissions from Palm and Jatropha feedstock as a fuel in diesel engine. There are many ways to be used in diesel engine such as emulsified with water, added catalyst, blended with diesel fuel at certain proportion or directly used in the engine. Therefore, many studies need to be done in order to understand the characteristic of these biodiesel before it can be fully implemented in diesel engine.

ACKNOWLEDGEMENT

The author would like to thank the Ministry Of Higher Education (MOHE), Research Management Institute (RMI) of Universiti Teknologi Mara (UiTM), Malaysia through FRGS grant awards (600-RMI/ST/FGRS 5/3Fst (32/2011), (600-RMI/ST/FRGS 5/3/FST (103/2010)) and also to MyBrain PHD.

REFERENCES

Abdullah, A. Z., Salamatinia, B., Mootabadi, H., & Bhatia, S. (2009). Current status and policies on biodiesel industry in Malaysia as the world's leading producer of palm oil. *Energy Policy, 37*(12), 5440-5448. doi: 10.1016/j.enpol.2009.08.012

Ahmad, A. L., Yasin, N. H. M., Derek, C. J. C., & Lim, J. K. (2011). Microalgae as a sustainable energy source for biodiesel production: A review. *Renewable and Sustainable Energy Reviews, 15*(1), 584-593. doi: 10.1016/j.rser.2010.09.018

Akbar, E., Yaakob, Z., Kamarudin, S. K., Ismail, M., & Salimon, J. (2009). Characteristic and composition of jatropha curcas oil seed from Malaysia and its potential as biodiesel feedstock. *European Journal of Scientific Research, 29*(3), 396-403.

Atabani, A. E., Silitonga, A. S., Badruddin, I. A., Mahlia, T. M. I., Masjuki, H. H., & Mekhilef, S. (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renewable and Sustainable Energy Reviews, 16*(4), 2070-2093. doi: 10.1016/j.rser.2012.01.003

Azhari, Faiz, M., Yunus, R., Ghazi, T. I. M., & Yaw, T. C. S. (2008). *Reduction of free fatty acids in crude jatropha curcas oil via an esterification process.* Paper presented at the International Journal of Engineering and Technology.

Baitiang, T., Suwannakit, K., Duanmukpanao, T., Sukjamsri, C., Topaiboul, S., & Chollacoop, N. (2008). Effects of biodiesel and jatropha oil on performance, black smoke and durability of single-cylinder diesel engine. *Journal of Metals, Materials and Minerals, 18*(2), 181-185.

Bora, D. K., Baruah, D. C., Das, L. M., & Babu, M. K. G. (2012). Performance of diesel engine using biodiesel obtained from mixed feedstocks. *Renewable and Sustainable Energy Reviews, 16*(8), 5479-5484. doi: 10.1016/j.rser.2012.06.026

Chauhan, B. S., Kumar, N., Du Jun, Y., & Lee, K. B. (2010). Performance and emission study of preheated Jatropha oil on medium capacity diesel engine. *Energy, 35*(6), 2484-2492. doi: 10.1016/j.energy.2010.02.043

Chin, M. (2011). Biofuels in Malaysia: An analysis of the legal and institutional framework. *Working Paper 64*. Retrieved from CIFOR website:

Choudry, A. R., Karmakar, R., K.Kundu, & Dahake, V. R. (2011)). "Algal" biodiesel : Future prospects and problems. *Water & Energy International, (Renewable Energy Section)*. Retrieved from

Economic Benefits of Algae. from http://algae.ucsd.edu/potential/economic-benefits.html

Elango, T., & Senthilkumar, T. (2011). Performance and emission characteristics of CI engine fuelled with non-edible vegetable oil and diesel blends. *Journal of Engineering Science and Technology 6*(2), 240 - 250.

Hoekman, S. K., & Robbins, C. (2012). Review of the effects of biodiesel on NOx emissions. *Fuel Processing Technology, 96*, 237-249. doi: 10.1016/j.fuproc.2011.12.036

Jindal, S., Nandwana, B. P., & Rathore, N. S. (2010). A comparative study of performance, combustion and emissions of Diesel, Jatropha Methyl Ester and Karanj Methyl Ester in a DI-CI Engine. *Journal of Biofuels, 1*(1), 20-29.

Juan, J. C., Kartika, D. A., Wu, T. Y., & Hin, T. Y. (2011). Biodiesel production from Jatropha oil by catalytic and non-catalytic approaches: an overview. [Research Support, Non-U.S. Gov't Review]. *Bioresour Technol, 102*(2), 452-460. doi: 10.1016/j.biortech.2010.09.093

Kalam, M. A., Ahamed, J. U., & Masjuki, H. H. (2012). Land availability of Jatropha production in Malaysia. *Renewable and Sustainable Energy Reviews, 16*(6), 3999-4007. doi: 10.1016/j.rser.2012.03.025

Kamei, W., Singh, I. P., Sharma, M. L., Singh, K., & Singal, S. K. (2010). Performance and emissions of biodiesel blends in an automotive diesel engine. *Journal of Biofuels, 1*(1), 92-96.

Koh, M. Y., & Mohd. Ghazi, T. I. (2011). A review of biodiesel production from Jatropha curcas L. oil. *Renewable and Sustainable Energy Reviews, 15*(5), 2240-2251. doi: 10.1016/j.rser.2011.02.013

Lapuerta, M., Armas, O., & Rodriguezfernandez, J. (2008). Effect of biodiesel fuels on diesel engine emissions. *Progress in Energy and Combustion Science, 34*(2), 198-223. doi: 10.1016/j.pecs.2007.07.001

Liaquat, A. M., Kalam, M. A., Masjuki, H. H., & Rezza, A. (2010). An experimental study on exhaust emissions of a diesel engine using jatropha oil and palmdiesel with diesel fuel. *Sci.Int(Lahore)*, 245-249.

Lim, T. H., Bari, S., & Yu, C. W. (2002). Using crude palm oil (CPO) as diesel engine fuel. *ASEAN Journal on S&T for Development (AJSTD), 19*(2), 1-13.

Mamat, R., Rahim, R., Abdullah, A. A., Aziz, A., & Abdullah, N. R. (2012). Characteristic of biodiesel fuel derived from palm oil. *Journal of Biobased Materials and Bioenergy, Vol. 6*, pp. 1-4.

Mekhilef, S., Siga, S., & Saidur, R. (2011). A review on palm oil biodiesel as a source of renewable fuel. *Renewable and Sustainable Energy Reviews, 15*(4), 1937-1949. doi: 10.1016/j.rser.2010.12.012

Ministry of plantation industries and commodities, Malaysia. http://www.americanpalmoil.com/pdf/biodiesel/Malaysia%20Biofuel%20Policy.pdf.

Mofijur, M., Masjuki, H. H., Kalam, M. A., Hazrat, M. A., Liaquat, A. M., Shahabuddin, M., & Varman, M. (2012). Prospects of biodiesel from Jatropha in Malaysia. *Renewable and Sustainable Energy Reviews, 16*(7), 5007-5020. doi: 10.1016/j.rser.2012.05.010

Narkpakdee, J., Permsuwan, A., Deethayat, T., & Kiatsiriroat, T. (2012). Performance and Emission of Small Diesel Engine Using Diesel-Crude Palm Oil-Water Emulsion as Fuel. *Energy Science and Technology, 3*(2), 38-45. doi: 10.3968/j.est.1923847920120302.279

Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., & Honnery, D. (2012). Life cycle cost and sensitivity analysis of palm biodiesel production. *Fuel, 98*, 131-139. doi: 10.1016/j.fuel.2012.03.031

Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., & Norhasyima, R. S. (2011). Comparison of palm oil, Jatropha curcas and Calophyllum inophyllum for biodiesel: A review. *Renewable and Sustainable Energy Reviews, 15*(8), 3501-3515. doi: 10.1016/j.rser.2011.05.005

Pandey, S., Sharma, A., & Sahoo, P. K. (2012). Experimental investigation on the performance and emission characteristics of a diesel engine fuelled with ethanol, diesel and jatropha based biodiesel blends. *International Journal of Advances in Engineering & Technology*.

Reksowardoj, I. K., Lubis, I. H., S.A., W. M., Brodjonegoro, T. P., Tatang H. Soerawidjaja, Arismunandar, W., . . . Ogawa, H. (2007). Performance and Exhaust Gas Emissions of Using Biodiesel Fuel from Physic Nut (Jatropha Curcas L.) Oil on a Direct Injection Diesel Engine (DI). *Copyright © 2007 Society of Automotive Engineers of Japan, Inc. and Copyright © 2007 SAE International*. doi: JSAE 20077278

Sahoo, P. K., & Das, L. M. (2009). Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine. *Fuel, 88*(6), 994-999. doi: 10.1016/j.fuel.2008.11.012

Sahoo, P. K., Das, L. M., Babu, M. K. G., Arora, P., Singh, V. P., Kumar, N. R., & Varyani, T. S. (2009). Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. *Fuel, 88*(9), 1698-1707. doi: 10.1016/j.fuel.2009.02.015

Salamanca, M., Mondragón, F., Agudelo, J. R., & Santamaría, A. (2012). Influence of palm oil biodiesel on the chemical and morphological characteristics of particulate matter emitted by a diesel engine. *Atmospheric Environment, 62*, 220-227. doi: 10.1016/j.atmosenv.2012.08.031

Tan, P.-q., Hu, Z.-y., Lou, D.-m., & Li, Z.-j. (2012). Exhaust emissions from a light-duty diesel engine with Jatropha biodiesel fuel. *Energy, 39*(1), 356-362. doi: 10.1016/j.energy.2012.01.002

Yusop, A. F., Mamat, R., Sudrajad, A., & Yasin, M. H. M. (2012). Characteristics of Particulate Matter (PM) of Diesel engine using Palm Oil Methyl Ester (PME) fuel. *Journal of Biobased Materials and Bioenergy, vol. 6*, pp. 1-4.

Yusuf, N. N. A. N., Kamarudin, S. K., & Yaakub, Z. (2011). Overview on the current trends in biodiesel production. *Energy Conversion and Management, 52*(7), 2741-2751. doi: 10.1016/j.enconman.2010.12.004.