

## BIODIESEL FROM JATROPHA CURCAS LINNAEUS AND ITS PERFORMANCE AS BLENDS IN DIESEL ENGINE

Abu Saleh Ahmed<sup>1</sup>, Sarfaraj Khan<sup>1</sup>, Md. Tofajjal Hossain Chowdhury<sup>2</sup> and Sinin Hamdan<sup>1</sup>

<sup>1</sup>Department of Mechanical & Manufacturing Engineering, Universiti Malaysia Sarawak, Malaysia,

<sup>2</sup>Department of Mechanical Engineering, Primeasia University, Bangladesh.

### ABSTRACT

The efforts in exploring new renewable energy sources become crucial as solutions in resolving the crisis of the depleting mineral sources. Biodiesel had been identified as one of the solution and *Jatropha curcas* Linnaeus (JCL) is a potential source of biodiesel. The purpose of this study was to investigate the efficiency of biodiesel conversion from Crude *Jatropha* Oil (CJO) into *Jatropha* Biodiesel (JB) through the method of transesterification. Both one-step and two-steps methods were performed but only the latter method able to convert successfully. Besides, the biodiesel produced were tested through Fourier Transform Infrared Spectrometer (FT-IR) on the components. The biodiesel were then blended with mineral diesel at various mixing percentage before the mixtures are applied as the fuel source for a diesel engine performance test. As the result, 20% JB blends in mineral diesel performs at compatible level with pure mineral, with the lowest fuel consumption rate and specific fuel consumption and higher brake horsepower.

**Keywords:** *Jatropha Curcas* Linnaeus, Biodiesel, Transesterification, Fourier Transform Infrared Spectrometer (FT-IR), Engine Performance.

### 1. INTRODUCTION

*Jatropha curcas* Linnaeus (Euphorbiaceae)-JCL, is a shrub or tree originates from Mexico and Central America, by J. Heller in [1], known as physic nut and locally as pokok jarak pagar [2]. This plant producing non-edible oily seed found and now cultivated for biofuel in Asia and Africa. It is known as a plant that has the ability to grow well in any nature of soils including foothills [3], drought resistant best under average rainfall 900-1200 mm/yr [4] and persistent plant grows up to fifty years [5]. Generally, every part of the tree has a multiple usage which can be converted into valuable products such as the seeds (biofuel, glycerol, medical use, detoxified animal feed), fruit and seed waste (biomass and fertilizer) [6]. Biodiesel from JCL has been the answer to the global energy crisis in this day of sky-rocketing fuel prices and scarcity of global supply in which at the same time meeting the standards of US, Germany and European Standard Organization. JCL seeds contain averagely 30-35% oil by weight (Pramanik K in [7]), which can easily be converted into bio-diesel through a process called transesterification. Transesterification can be defined as a displacement of alcohol from an ester by another alcohol (L.C. Meher et.al (2006) in [1]. It is clear that the *Jatropha* Biodiesel (JB) has a higher flash point and cloud point compared to

fossil diesel. The higher the flash point, the safer is the fuel [8, 9]. Relative to low sulphur diesel, emission reductions from a 10% biodiesel/diesel blend are expected to be 2.4% in carbon monoxide, 2.0% in non-methane volatile organic compounds (NMVOC) and 2.3% in particulate matter [10]. On 1997, Kyoto Protocol (KP) was established by UNFCCC to focus on moves in reducing greenhouse gases (GHG) including Methane (CH<sub>4</sub>), Nitrous oxide (N<sub>2</sub>O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF<sub>6</sub>) [11]. European Union (EU), another body sharing the same commitment with KP is offering some scheme such as emission trading scheme for industries to follow in order to achieve emission – reduction target in line with cost reduction [12]. Since 2008, India had introduced a new policy of the requirement of 20 percent blends of biodiesel in transportation industry by 2017 [13]. While starting from 2010, Brazilian's diesel-operated vehicle must run on mandatory of 5% blends of biodiesel, announced by the president, Luiz Inácio Lula da Silva [14]. Moreover, European Union (EU) is awarding Certified Emission Reductions (CER) to companies using biodiesel from JCL since it has been proven to be zero carbon dioxide emitting sources. One hectare of JCL could result in CO<sub>2</sub> emissions reductions of 10 tonnes per year [Francis and Becker 2001 in [15]]. JCL

helps in sequestration of atmospheric carbon and assists in the built up of total soil carbon [16]. Hence, it's assisting the effort in reducing one of the element that lead to the formation of green house effects gases.

The objectives of this paper are to outline and calibrate variables and parameters affecting a transesterification process in converting CJO to JB, to interpret the content in JB produced compared to the other biodiesel source and mineral diesel through Fourier Transform Infrared (FT-IR) Analysis and to study on the performance parameters of the diesel engine running on JB blends in various mixing percentage and choose the most optimum blends.

## 2. MATERIALS AND METHODS

CJO used in this experiment was obtained from a local company in Sarawak, Alam Widuri Sdn. Bhd. The experiments consisted of three parts: one-step and two-steps transesterification and diesel engine test. Three equipments were tested, namely mixing stirrer cum heater, autoclave and orbital shaker.

### 2.1 One-Step Transesterification

First of all, the CJO purchased was filtered using the filter funnel and filter paper. The filtered oil was pre-treated through heating up to 100°C to remove the water content [17]. To prepare the methoxide mixture, methanol was mixed with potassium hydroxide. Different methanol to oil ratios by weight and potassium hydroxide to oil ratios were used to investigate their influence the performance of the conversion. The methoxide mixture was heated until 50°C, and mix in the heated CJO. For magnetic stirrer cum heater, mixture was allowed to stir for 3 hours while the temperature was maintained at 60°C. For orbital shaker, mixture was allowed to shake for 3 hours at room temperature. Using autoclave, mixture was allowed to be heated under pressure for 3 hours. After the 3 hours of reaction, mixture was left to settle overnight to separate the glycerol layer. After settlement, lower layer of glycerol was removed. The upper layer of the methyl ester fraction was washed using water bath to remove impurities.

### 2.2 Two-Steps Transesterification

The first step of the process was done to remove the content of high free-fatty acid (FFA)s in the crude oil [18]. The solution of sulphuric acid in methanol was heated until 50°C. Different methanol to oil ratios by weight and sulphuric acid to oil ratios were studied. Acid values in pH were measured, and allow the mixture to react for two hours. This can be done by using the magnetic stirrer or orbital shaker. The mixture was left to settle for 1 hour before the upper layer of methanol-water fraction was removed. Get the lowest acid value of oil product at the lower layer for the next reaction.

Second step was performed to find the optimum condition for conversion and to investigate the potassium hydroxide to oil ratios and methanol to oil ratios. Oil product from step 1 was heated until it turns into clearer

fluid reaching temperature 50°C. Meanwhile, the solution of KOH in MeOH at different ratios to the oil was also heated until 50°C before they are added into the heated oil product. Using magnetic stirrer, mixture was allowed to be heated at 65°C and stirred for 2 hours. For orbital shaker, the mixture was allowed to shake at 250 rpm for 4 hours. For autoclave, mixture was heated under pressure for 2 hours. After settlement overnight, glycerol layer are removed. Then, remove the upper layer of the methyl ester fraction. The upper layer of the methyl ester fraction was washed using water bath to remove impurities. Clear biodiesel was obtained by heating the washed oil product.

### 2.3 Fourier Transform Infrared Spectrometer (FT – IR) Analysis

IRAffinity-1 from Shimadzu is used as the FT – IR Spectrometer. Samples of JB, mineral diesel, coconut biodiesel and algae biodiesel is prepared and tested using the equipment. The graphs of the spectrum absorptions are obtained and the identification of presence group are performed.

### 2.4 Diesel Engine Performance Test

The engine performance test was carried for JCL biodiesel blend with a variable speed range from 800 to 3600 rpm with 50% throttle position in ISUZU-4FB1 model diesel engine. The important engine specifications were given in table-1.

Table-1: Specification of Diesel Engine

Engine	: ISUZU
Model	: 4FB1
Type	: Water-cooled, four stroke
Combustion	: Indirect injection (IDI)
Number of cylinders	: 4
Bore × Stroke	: 84 × 82 mm
Displacement	: 1817 cc
Compression Ratio	: 21 : 1
Nominal Rated Power	: 39 kW/5000 rpm
Maximum Torque speed	: 1800 – 3000 rpm
Combustion Chamber	: Swirl Chamber
Nozzle Type	: Throttle
Cooling System	: Pressurized circulation

## 3. RESULTS AND DISCUSSIONS

### 3.1 One-Step Transesterification

As a control experiment, one – step method is carried out under different ratios and equipment. However, the product from the procedure is either solidified oil waste or fully glycerine by-product. No successful conversion is being observed. Observed oil textures and smells are similar to the crude oil. Therefore, for CJO, conversion through single step is incomplete and totally inefficient. It may due to the presence of free-fatty acid (FFAs) that react with base catalyst to form soaps, resulting in serious emulsification and separation problems. The percentage of FFAs in CJO may increase due to the hydrolysis of triglycerides in the presence of moisture and oxidations

due to improper handling and storage [19]. Degradation of the CJCO results higher concentration of FFAs.

### 3.2 Two-Steps Transesterification

The variables are defined and divided into three studies namely type of equipment, catalyst-to-oil ratio and alcohol-to-oil ratio.

#### 3.2.1 Production Process

Figure 1 shows the result of biodiesel conversion for the three equipments. Autoclave was not able to generate any JB. The contents of FFAs may not be removed in a pressurized, high temperature medium. Since the boiling point of methanol is around 65–70°C, the methanol should have evaporated before any reaction with the CJO and oil product was allowed. Hence, this method leads to a failure even in the first step. Meanwhile, by using mixing stirrer cum heater, the temperature can be controlled to be below 60°C, preventing the evaporation problem. However, the conversion efficiency falls between 60–72% only, which shows generation of significant amount of by-products. This may occur due to the imbalance mixing rate of the equipment itself, causing incomplete reaction to take place. As in orbital shaker which generates the highest conversion in the range 80–92%, the continuous and constant mixing rate lead to a better, more complete conversion than in the previous equipment. Even though the conversion is unable to generate stable output since temperature control is not applied, it is proven that the parameter of mixing rate is more important than the process temperature.

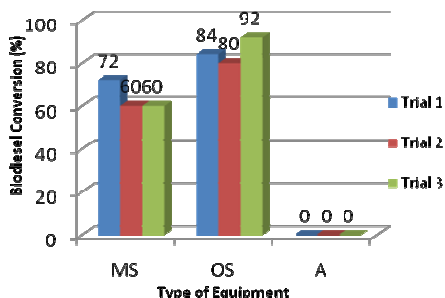


Fig 1. Biodiesel conversion by different type of equipment with 2:1 methanol to oil and 0.04:1 acid to oil for step 1, and 4:1 methanol to oil and 0.02:1 base to oil for step 2.

#### 3.2.2 Catalyst-to-Oil Ratio

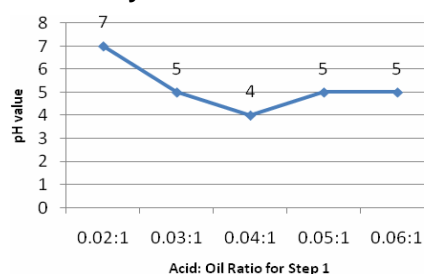


Fig 2. Acid value in pH at different acid to oil ratio with 2:1 methanol to oil in step 1.

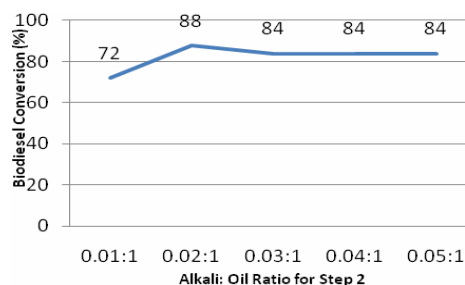


Fig 3. Biodiesel conversion by changing base:oil in step 2 with 2:1 methanol to oil and 0.04:1 acid to oil for step 1, and 4:1 methanol to oil for step 2.

From Figs. 2-3, the ratio of 0.04:1 is able to give the lowest acid value in pH while the optimum base catalyst-to-oil ratio is 0.02:1 and able to assist the conversion of 88% of CJO into JB. The extra addition of the catalyst did not improve the efficiency and the addition of excess amount of it gave rise to the formation of emulsion, which increased viscosity, lead to the formation of gels and the problem associated with glycerin separation and loss in ester yield [19].

#### 3.2.3 Alcohol-to-Oil Ratio

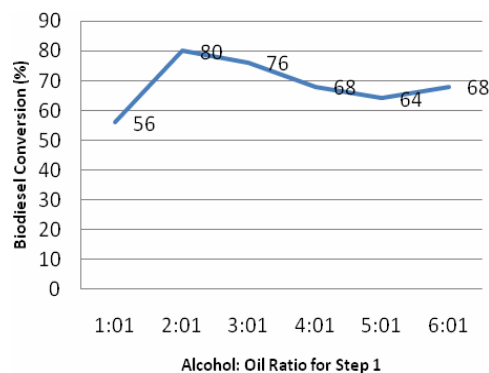


Fig 4. Biodiesel conversion by changing alcohol: oil in step 1 with 0.04:1 acid to oil for step 1, and 4:1 methanol to oil, 0.02:1 base to oil for step 2.

In accordance to [18, 19], the selected range for MeOH: CJO ratio is from 1:1 until 6:1 to promote completion of reaction. The results show that the most optimum ratio for step 1 is 2:1. The function of methanol in this step is to remove the water content and FFAs in CJO. It is shown that 6:1 ratio shows little increment again. It is predicted that the conversion might keep improving. However, this might not be as economical for practice since the improvement is compatible to the conversion of 2:1.

Figure 5 shows the conversions increase with the increase of methanol content, until it reaches 5:1. Additional methanol will be found in the oil product from the Step 2 which is then removed through water bath. As experiment proceeds, there is no improvement observed in the conversion percentage. Even though it is predicted that conversion may increase at a small step,

the choice may no longer be commercially economical and practicable.

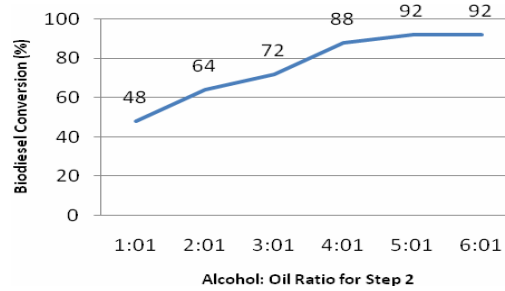


Fig 5. Biodiesel conversion by changing alcohol: oil in step 2 with 2:1 methanol to oil, 0.04:1 acid to oil for step 1, and 0.02:1 alkali to oil for step 2.

CJO appears to have a darker yellow colour compared to JB while JB is clearer than its crude oil, having an obviously less viscous texture when it is poured. The smells of the oils are roughly the same. A simple test on both CJO and JB for burning and from naked eyes observation, the both oils show light emission of smoke. Burning of JB is more complete lead to greater flame. Figure 6 shows the direct burning testing on both oils.

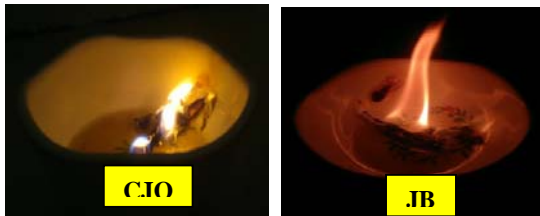
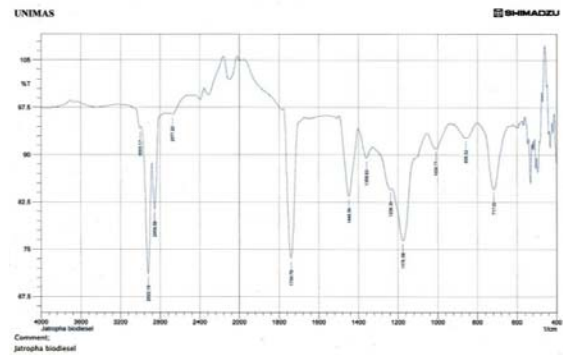


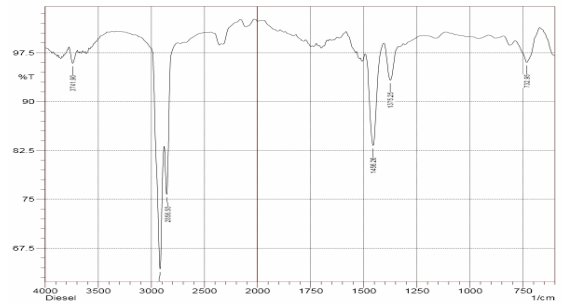
Fig 6. Burning Testing on CJO and JB Samples.

### 3.3 Fourier Transform Infrared Spectrometer (FT-IR) Analysis Result

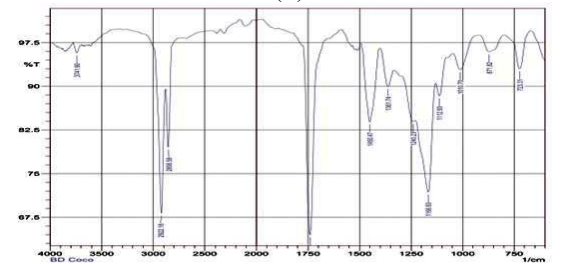
The spectrum patterns of all the biodiesel sources and mineral diesel fall between the spectrum ranges from  $600\text{cm}^{-1}$  to  $4000\text{cm}^{-1}$ . The peaks represent each group of elements or compounds. First of all, the first three peaks, which are  $717.52\text{cm}^{-1}$ ,  $858.32\text{cm}^{-1}$  and  $1008.77\text{cm}^{-1}$  can be categorized as aromatic hydrocarbons. The fourth and the fifth peak ( $1176.58\text{cm}^{-1}$  and  $1238.3\text{cm}^{-1}$ ) are classified as carbon – oxygen (C-O bonds absorption). The peak at  $1359.82\text{cm}^{-1}$  is from methyl group ( $\text{CH}_3$ ) while peak at  $1448.54\text{cm}^{-1}$  is classified as a bending absorption of methylene ( $\text{CH}_2$ ) [20]. A peak at  $1739.79\text{cm}^{-1}$  shows the presence of ester carbonyl bond or known as aldehyde ( $\text{C}=\text{O}$ ) which proves that this specimen is a fatty acid methyl ester (FAME) or known as biodiesel. This is different from mineral diesel that shows no peak in the range. Meanwhile, the peaks at  $2922.16\text{cm}^{-1}$  and  $3003.17\text{cm}^{-1}$  located in the range of  $3100\text{cm}^{-1}$  until  $2700\text{cm}^{-1}$  for C – H bond absorption [21, 22]. The stretching absorption of (O-H) at  $3741.9\text{cm}^{-1}$  is obtained in both CB and AB due to the water content in the specimen. This stretching (O-H) absorption is intermolecular hydrogen bonding for water [23].



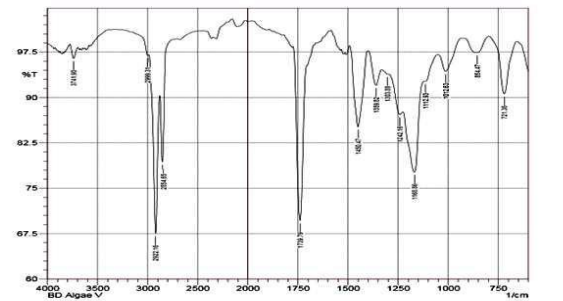
(i)



(ii)



(iii)



(iv)

Fig 7. FT – IR Spectrum for (i)JB, (ii)Mineral Diesel, (iii)Coconut Biodiesel and (iv)Algae Biodiesel.

### 3.4 Diesel Engine Performance Test

For safe operation of diesel engine, the highest biodiesel blend was selected B30 (70 % conventional diesel oil and 30 % JCL biodiesel by volume). The engine performance data for biodiesel blends are shown in table-2 and Table-3 . In figure-8 the fuel consumption versus biodiesel blends from B0 to B30 were shown. The specific fuel consumption increased as the percentage of biodiesel blend was increased. This was happened due to the lower energy content in biodiesel compared to the conventional diesel [24, 25].

Table -2: Engine Performance Data for Biodiesel Blend.

Fuel	*GHV (MJ/kg)	Fuel (ml)	Speed (RPM)	Time (sec)
B0	44.56	20	1436	134
B5	44.17	20	1436	133
B10	43.84	20	1435	133
B15	43.68	20	1434	133
B20	43.25	20	1433	132
B25	42.97	20	1432	132
B30	42.44	20	1430	131

\*GHV- Gross Heating Value of Fuel

Table -3: Engine Performance Data for Biodiesel Blend

Fuel	**FCR (ml/100 sec)	Engine Power Output(kW)	***SFC (ml/Watt t)
B0	14.9	1.709	11.7
B5	15.0	1.709	11.7
B10	15.0	1.693	11.8
B15	15.0	1.682	11.89
B20	15.1	1.682	11.89
B25	15.1	1.671	11.97
B30	15.2	1.665	12.01

\*\*FCR- Fuel Consumption Rate.

\*\*\*SFC- Specific Fuel Consumption with respect to Engine Power Output

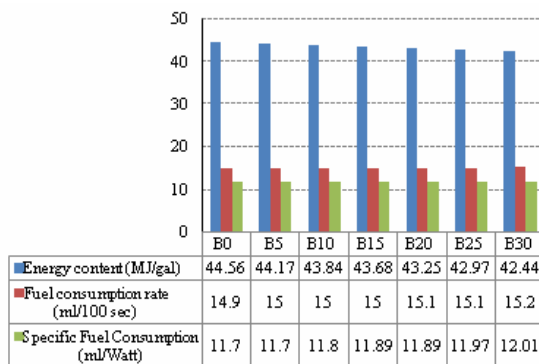


Fig 8. Fuel Consumption Rate of Diesel Engine for Different Biodiesel Blend

In engine performance test of biodiesel blend, the brake power of diesel engine was compared between OD (Ordinary Diesel) and biodiesel blend A (B20) in figure-9. The brake power increased as increasing the speed up to 1600RPM for both fuel OD and A. After that it decreased as increasing the speed for both fuel. Fuel A showed the higher brake power due to its superior lubricity and better combustion criteria [26].

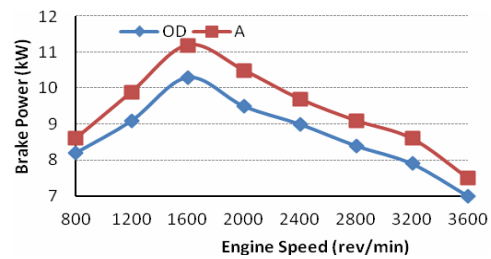


Fig 9. Brake Power (kW) vs. Engine Speed (rpm)

#### 4. CONCLUSION

In engine performance test, the specific fuel consumption rate was increased as JB biodiesel percentages increased in fuel blend due to less energy content in biodiesel. This is mainly due to the relationship among volumetric fuel injection system, fuel specific gravity, viscosity and heating value. Biodiesel blend showed higher brake power in variable speed due to the superior lubricity of biodiesel. Thus these results proved that the JCL biodiesel have almost similar fuel efficiency as compared to petroleum diesel.

#### 5. REFERENCES

1. B. M. W. Achtena, E. Mathijsb, V.P. Singhc and L. Verchot. Life-cycle Assessment of Bio-diesel from *Jatropha curcas L.* Energy Balance, Impact on Global Warming, Land Use Impact. Available: [http://www.biofuel-africa.org/phocadownload/docs/en\\_achten-biodiesel-ACV.pdf](http://www.biofuel-africa.org/phocadownload/docs/en_achten-biodiesel-ACV.pdf)
2. A. K. G. K.C. Verma, "Jatropha curcas L.: Substitute for Conventional Energy," *World Journal of Agricultural Sciences* vol. 5, pp. 552-556, 2009.
3. Haq, A. K. Shikha Roy. *Jatropha Curcas: A Potential Plant for Bio-Fuel* [Online]. Available: [http://www.science20.com/humboldt\\_fellow\\_and\\_scienc/blog/jatropha\\_curcas\\_potential\\_plant\\_biofuel\\_1](http://www.science20.com/humboldt_fellow_and_scienc/blog/jatropha_curcas_potential_plant_biofuel_1)
4. S. H. G. Kritana Prueksakorn, "Energy and Greenhouse Gas Implications of Biodiesel Production from *Jatropha curcas L.*," presented at the The 2nd Joint International Conference on Sustainable Energy and Environment (SEE 2006), Bangkok, 2006.
5. R. S. V. Y.V.Hanumantha Rao, A.V.Sitarama Raju and P.Nageswara Reddy. Experimental investigations on jatropha biodiesel and additive in diesel engine [Online]. Available: <http://indjst.org/archive/vol.2.issue.4/apr09hanu.pdf>
6. K. Becker, Makkar, H.P.S. . *Jatropha and Moringa* [Online]. Available: <http://www.unihohenheim.de/~www480/docs/se990720/jatropha.htm>
7. M. S. T. Arjun B. Chhetri, Suzanne M. Budge, K. Chris Watts and M. Rafiqul Islam (2008), Non-Edible Plant Oils as New Sources for Biodiesel Production *International Journal of Molecular Sciences* 9, 169-180. Available:

- <http://www.mdpi.net/ijms/papers/i9020169.doc>
8. Flash Point. Available: <http://www.ilpi.com/msds/ref/flashpoint.html>
  9. E. M. Association. *Recommended Guideline on Diesel Fuel*. Available: [http://www.tdiclub.com/articles/Diesel\\_Fuel\\_Guidelines/](http://www.tdiclub.com/articles/Diesel_Fuel_Guidelines/)
  10. P. D. John Stephenson, and Rebecca Schrage. (22 November 2004, Mandatory transport biofuels- Costs and benefits of mandatory biofuel blends in transport fuels. *Report to Ministry of Economic Development*. Available: <http://www.bioenergy.org.nz/documents/liquidbiofuels/mandatory-transport-biofuels.pdf>
  11. M. Bloch. Global warming - it's our choice" What is the Kyoto Protocol? [Online]. Available: <http://www.carbonify.com/articles/kyoto-protocol.htm>
  12. E. Communities. EU action against climate change [Online]. Available: [http://ec.europa.eu/environment/climat/pdf/emission\\_trading2\\_en.pdf](http://ec.europa.eu/environment/climat/pdf/emission_trading2_en.pdf)
  13. T. V. Padma. India approves biofuel rise [Online]. Available: <http://nation.ittefaq.com/issues/2008/09/29/news0790.htm>
  14. G. C. Congress. Brazil to Increase Mandatory Biodiesel Blend to 5% in 2010 - Mandatory Emissions Testing for Vehicles [Online]. Available: <http://www.greencarcongress.com/2009/10/brazil-b5-20091028.html>
  15. J. World. Clean Development Mechanism (CDM) [Online]. Available: [http://www.jatropha-world.org/carbon\\_credit\\_31.html](http://www.jatropha-world.org/carbon_credit_31.html)
  16. R. C. a. P. A. A. B. Anjan Kumar Prusty. Biodiesel: Freedom from Dependence on Fossil Fuels? [Online]. Available: <http://precedings.nature.com/documents/2658/version/1/files/npre20082658-1.doc>
  17. A. V. S. R. Y.V.Hanumantha Rao, P.Nageswara Reddy, R. Sudheer Voleti. (2009, Experimental Investigations on Jatropha Biodiesel and Additive in Diesel Engine. *Indian Journal of Science and Technology* [Research article]. 2(4), 25-32.
  18. Y. L. Houfang Lu, Hui Zhou, Ying Yang, Mingyan Chen, Bin Liang. (2008, Production of biodiesel from *Jatropha curcas L.* oil. *Computers and Chemical Engineering* 33, 1091-1096.
  19. S. H. Hanny Johanes Berchmans. (2007, Biodiesel Production from Crude *Jatropha curcas L.* Seed Oil with a High Content of Free Fatty acids. *Bioresource Technology* 99, 1716-1721.
  20. C.-P. S. Hsu. (n.d., Infrared Spectroscopy. *Handbook of Instrumental Techniques for Analytical Chemistry*, 247-283.
  21. M. Bradley. (2007, 12 March 2011). Biodiesel (FAME) Analysis by FT-IR. Available: [http://www.thermo.com/eThermo/CMA/PDFs/Articles/articlesFile\\_2448.pdf](http://www.thermo.com/eThermo/CMA/PDFs/Articles/articlesFile_2448.pdf)
  22. A. Rohman, Che Man, Y. B., Ismail, A. and Puziah. H., "FTIR spectroscopy combined with multivariate calibration for analysis of cod liver oil in binary mixture with corn oil," *International Food Research Journal*, vol. 18, pp. 736-740, 2011.
  23. Y. W. F. a. L. M. Y. W. Mahmood Mat Yunus, "Refractive Index and Fourier Transform Infrared Spectra of Virgin Coconut Oil and Virgin Olive Oil," *American Journal of Applied Sciences*, vol. 6, pp. 328-331, 2009.
  24. E. K. O. F.K. Forson, E. Hammond-Donkoh. (2004, Performance of jatropha oil blends in a diesel engine. *Renewable energy* 29, 1135-1145.
  25. M.A. Fazal, A.S.M.A. Haseeb and H.H. Masjuki. "Biodiesel Feasibility Study: An Evaluation of Material Compatibility, Performance, Emission and Engine Durability". *Renewable and Sustainable Energy Reviews* 15 (2011) 1314-1324
  26. M.H. Jayed , H.H. Masjuki, R. Saidur, M.A. Kalam and M.I. Jahirul. "Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia". *Renewable and Sustainable Energy Reviews* 13 (2009) 2452–2462

## 6. MAILING ADDRESS

**Dr. Abu Saleh Ahmed**  
 Senior Lecturer  
 Department of Mechanical & Manufacturing Engineering, Faculty of Engineering  
 Universiti Malaysia Sarawak  
 94300 Kota Samarahan  
 Sarawak  
 MALAYSIA  
**Phone :** +6082583299, + 60176308752(cell).  
**FAX :** +6082583410.  
**E-mail :** aasaleh@feng.unimas.my  
 saleh9703@yahoo.com