Techno-economic feasibility of Palm Fatty Acid Distillate (PFAD) blend as alternative to diesel fuel

Mantari M H A R¹, Hassim H M¹, Rahman R A¹, Zin A F M¹, Yahya M S¹, Samiran N A² and Asmuin N³

¹ Department of Mechanical Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia
² Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia
³ Department of Energy and Thermofluid, Faculty of Mechanical and Manufacturing, Universiti Tun Hussein Onn Malaysia

*Corresponding author: mhanafi@uthm.edu.my

Abstract. Palm oil had been as fuel in Malaysia with implementation of petroleum diesel and Palm Methyl Ester (PME) blend at 5% in 2014 and mandatory 10% blend in 2019. The high cost of the feedstock is the major drawback of PME. Not only PME comes from expensive low Free Fatty Acid (FFA) feedstock, the cost to convert FFA to PME through the process of transesterification and purification of palm oil fatty acid also expensive. Another feedstock for palm based biofuel is palm fatty acid distillate (PFAD). PFAD is a by-product of crude palm oil (CPO) refining. It is inedible and cheaper compared with other palm oil product thus attractive as a feedstock for biofuel. Five blends of PFAD and diesel with 5%, 10%, 15%, 20% and 25% were produce in this study. The blending was done using magnetic stirrer and was mix continuously for 30 minutes at 60 °C. The properties of the blends such as density, viscosity, surface tension, pour point and calorific value were determined experimentally. Result from these experiments showed that density, viscosity, surface tension and pour point were increase proportionately when PFAD content increase except for calorific value. The calorific value showed minor reduction with maximum reduction at 3% as compared with diesel fuel. This happen when the PFAD content was at 25% blend. In term of availability of PFAD as biofuel source, data from year of 2016 to 2019 showed that the amount of PFAD produce in Malaysia suffice to support 5% blends of PFAD as biofuel.

Keywords: palm fatty acid distillate, biofuel, free fatty acid, esterification, crude palm oil, feedstock, palm methyl ester.
1. Introduction

Oil palm is one of the cash crops that is widely planted in Malaysia and Indonesia which together account for 84% of palm oil produced in the world. The implementation of palm oil as fuel for transport and industrial use in Malaysia was mandatory in 2014 as B5 which contain blend of 95% petroleum diesel and 5% palm methyl ester and later upgraded to B10 which constitute 90% petroleum diesel and 10% palm methyl ester which mandatory for transportation sector on 1 February 2019 [1], [2]. On the other hand, Indonesian implementation of palm oil as fuel was compulsory on September 2018 at 20% blend of palm methyl ester while the rest is diesel fuel [3].

The palm methyl ester is produced from transesterification and purification of palm oil fatty acid and reacted with alcohol to produce palm methyl ester and glycerol [4]. The main drawback of palm oil biodiesel is the high producing cost of the product due to it is being produced from a high quality of virgin oil with low free fatty acid (FFA) contents. In order to overcome this limitation, the biodiesel product needs to be produced by using cheaper feedstock either from recycled/waste oils, or a by-product of refining vegetable oil that contains high FFA.

Source of feedstock that can be an alternative in producing the fuel from oil palm is by using palm fatty acid distillate (PFAD). The PFAD is a by-product of crude palm oil (CPO) from refining process. PFAD is inedible and much cheaper as compared to other palm oil product such as Refine, Bleach and Deodorized (RBD) palm olein and RBD palm stearin. From 2009 to 2015, PFAD always being traded at a discount as compared to RBD palm olein, RBD palm oil and palm stearin [5]. This factor coupled with inedibility and availability of palm oil resource in Malaysia makes it attractive as alternative feedstock for biofuel usage in Malaysia.

Generally, PFAD contains very high free fatty acid (FFA) that account from 65% until 95% and the remaining is triglyceride[6], [7]. The high contain of FFA requires two step operations that are esterification and transesterification reactions in order to convert it to become methyl ester [8], [9]. Another method to utilize PFAD as a biofuel source is to direct blend it with petroleum diesel. This process eliminates the needs of the costly operation of esterification and transesterification.

The use of a direct blend of palm oil product already been done by several researchers. The blends of Refine, Bleach and Deodorized Palm Olein (RBDPO) with petroleum diesel gave a performance on par with petroleum diesel in term of spray and combustion characteristics especially at lower blend (10% blend) [10] while the emission of NOx and CO reduce when the content of palm oil increased in the blend [11].

2. Biofuel Preparation

The PFAD was obtained from PGEO Sdn, Bhd, a subsidiary of Wilmar International. The quantity of each element in PFAD-diesel blend depends on its mixing ratio, for instance if B5, then it contains 95% of diesel fuel and 5% PFAD. The rest of the blend and its volumetric ratio are shown in table 1. Total one litre of PFAD-diesel blend were produced according to the designated blending ratio. The blending was done using magnetic stirrer at temperature 60°C and was stirred for 30 minutes in one litre glass beaker to allow the mixture to become homogenous.
Table 1. Composition of PFAD and diesel for each blend.

| Blends | PFAD (l) | Diesel (L) | Total (l) |
|--------|----------|------------|-----------|
| B0     | 0.00     | 1.00       | 1.00      |
| B5     | 0.05     | 0.95       | 1.00      |
| B10    | 0.1      | 0.9        | 1.00      |
| B15    | 0.15     | 0.85       | 1.00      |
| B20    | 0.2      | 0.8        | 1.00      |
| B25    | 0.25     | 0.75       | 1.00      |
| B100   | 1.00     | 0.00       | 1.00      |

Figure 1 shows the biofuel made from PFAD and diesel mixing. On the left hand side, is the diesel fuel, B0 followed by B5, B10, B15, B20, B25 and lastly B100 (100% PFAD). It is clearly shown that the colour of the blend is getting darker when the percentage of PFAD is increased in the blend. On the other hand, PFAD remain in solid form in a room temperature.

3. Physico-Chemical Properties of PFAD-Diesel Blend

The physical and chemical properties of PFAD-Diesel blend were being experimentally determined in this study. Five properties of PFAD-Diesel blend that are density, viscosity, surface tension, pour point and calorific value were determined. Figure 2 shows the density for each blend of PFAD-diesel. It showed that the density increases when the PFAD content in the blend is increased. This clearly shown that the higher density of PFAD contributes greatly towards the density of the blend. High in atomic mass means that the atoms arrangement of PFAD-Diesel blend is much closely-packed as the amount of PFAD in the blend keep increasing thus resulted in increase in density of the blend.

Figure 3 shows the kinematics viscosity of PFAD based biofuel. It could be shown that the kinematics viscosity of PFAD-Diesel blend is marginally increased from B5 and B10. The graph showed a tremendous increment starting from B10 until B25. This shows that the shear resistance in PFAD-Diesel blend keep increasing as the PFAD content in the blend increases. The PFAD contributes significantly towards the inter-molecular friction that is exerted whenever the layers of the PFAD-blend attempt to slide to each other.
The surface tension test was conducted for PFAD-Diesel blend to identify its surface property that resists towards any external force. This property depends on the molecule cohesive nature. Therefore, after conducting the test, the surface tension recorded data are tabulated and shown in figure 4.

Figure 4 clearly shows that the surface tension of PFAD-Diesel blend increases as the PFAD content in the blend is increased. There is a significant increment in surface tension value from B0 to B5, and from B5 until B20, the value increase steadily. This shows that the intermolecular force of PFAD-Diesel blend keeps increasing as the PFAD content increases. Large intermolecular force contributes towards the bonding strength between molecules at the liquid surface.

Figure 5 shows the pour point of PFAD-Diesel blend. Pour point is a property in which represents the lowest temperature at which oil is capable to flow under gravity pull. It can be shown that diesel fuel can still flow at sub-zero temperature. The increase of PFAD content on the blend reduces the capability of the biofuel blend to flow at low temperature. The lowest temperature for the blend to flow under gravity is 24°C for B20 and B25.
Figure 6 shows the calorific value (CV) of PFAD and Diesel blend. Calorific value is the amount of energy produced by the complete combustion of a material or fuel. Diesel fuel has the highest calorific value which is 45.25 MJ/kg and PFAD is the lowest at 38.90 MJ/kg. The decrease in calorific value can be seen in figure 6 as the amount of PFAD increases in the blend. At 25% blending ratio, the calorific value was reduced around 3% as compared to diesel fuel while for the rest of the blending ratio recorded insignificant reduction in CV as compared to diesel fuel.
4. Availability of PFAD as Biofuel

The feedstock for biofuel should be widely available and low price to make it suitable for commercialize use. Figure 7 shows the production and average monthly stock of PFAD at palm oil refinery for seven years from year of 2012 to 2018.

It can be seen that the amount of PFAD produced by refinery in Malaysia is in the range of 650 to 782 kilotons annually for the 7 years which average production stood at 697 kilotons. The monthly average stock of PFAD at palm oil refinery varies from the lowest 47 kilotons to the highest at 81 kilotons while average for seven years is 61 kilotons. In a percentage perspective, about 8.7% of PFAD produced by refinery lies as stock.

Figure 6. Calorific value of PFAD-diesel blend.

Figure 7. Production and monthly average stock of PFAD [12].
Table 2 shows the annual consumption of diesel fuel in Malaysia from year 2012 to 2016. The average annual consumption of diesel fuel in five years is 9.6 mtoe (million tonnes of oil equivalent). If the government of Malaysia enforces the usage of PFAD in diesel fuel at 5%, as much as 477.7 ktoe (kilo tonnes of oil equivalent) PFAD will be required annually. However, the average amount of PFAD required will increase to 955.4 ktoe for 10% PFAD and finally to 2.4 mtoe if 25% PFAD added to the diesel fuel.

Average production and stock of PFAD for year 2012 to 2016 as shown in figure 7 stood at 666.7 ktons and 57.9 ktons respectively. The implementation of PFAD in diesel fuel at least 5% can result in surge demand of PFAD thus can eliminate the excess stock of PFAD in refinery.

The increase in demand will increase the price of PFAD thus bring additional profit to the palm oil industry and bring another sustainable revenue for the country as seen in the case for implementation of B10 Biodiesel in Malaysia [4].

At 5% PFAD in diesel fuel, it will consume about 71.7% from total average production of PFAD in Malaysia for the year of 2012-2016. If the mandate goes to 10% PFAD, the amount of PFAD required to fulfil the demand of average diesel fuel consumption is 955.4 ktoe while the average production of PFAD only 666.7 ktons, thus creating shortage of PFAD.

5. Price Comparison of PFAD with respect to others Palm Oil Product

The benefit of using PFAD as biofuel feedstock is its low price. Previous study showed that for year of 2009 and 2015, PFAD always traded below the price of other palm oil product such as Refine Bleach and Deodorized (RBD) Palm Oil, RBD Palm Olein and RBD Palm Stearin [7].

Latest data from Malaysia Palm Oil Board (MPOB) suggested the same occurrence as shown in table 3. For the year of 2016, 2017 and 2018, the export price of PFAD traded always at a discount as compared to RBD Palm oil, RBD Palm Olein and RBD Palm Stearin on a monthly basis.

Year of 2017 showed the price for all of the palm oil product surged to the highest as compared to 2016 and 2018. The price difference for PFAD as compared to the RBD oil, olein and stearin in the year of 2017 were USD34, USD49 and USD22 per ton respectively. As mentioned earlier, the price of PFAD was USD22 per ton lower than RBD Palm Stearin in the year of 2017 which translate at 3% discount while at year of 2018, the price gap between Palm Stearin and PFAD getting wider to USD 74 per ton which is 15.5% lower as respect with Palm Stearin.

| YEAR    | 2012  | 2013  | 2014  | 2015  | 2016  | Avg  |
|---------|-------|-------|-------|-------|-------|------|
| DIESEL  | 9,410.00 | 9,568.00 | 10,161.00 | 9,377.00 | 9,254.00 | 9,554.00 |
| IF 5% PFAD | 470.50 | 478.40 | 508.05 | 468.85 | 462.70 | 477.70 |
| IF 10% PFAD | 941.00 | 956.80 | 1,016.10 | 937.70 | 925.40 | 955.40 |
| IF 15% PFAD | 1,411.50 | 1,435.20 | 1,524.15 | 1,406.55 | 1,388.10 | 1,433.10 |
| IF 20% PFAD | 1,882.00 | 1,913.60 | 2,032.20 | 1,875.40 | 1,850.80 | 1,910.80 |
| IF 25% PFAD | 2,352.50 | 2,392.00 | 2,540.25 | 2,344.25 | 2,313.50 | 2,388.50 |
6. Conclusion
Five blends of petroleum diesel and PFAD were prepared for this study starting with 5% PFAD, followed by 10%, 15%, 20% and lastly 25%. The rest constituent in the blend is diesel. Physical and chemical properties of the blends were determined experimentally. The properties are density, kinematics viscosity, surface tension, pour point and calorific value. The result showed that the increase in PFAD content in the blend increase the density, kinematics viscosity and surface tension while the ability of the blend to flow at colder temperature decrease significantly as the content of PFAD increase. On the other hand, since PFAD has a lower calorific value as compared to diesel, the PFAD-Diesel blend showed maximum 3% decrease in calorific value at 25% blending ratio while for the rest of the blending ratio recorded insignificant reduction (around 1%) in calorific value as compared to diesel fuel. In term of availability of PFAD as biofuel feedstock, at 5% of PFAD in diesel fuel, the amount of PFAD produced is sufficient to accommodate the demand of average diesel fuel for the case of diesel consumption from year 2012 to 2016. The price of PFAD always traded at discount as compared to other palm oil product, make it attractive for biofuel production.

Table 3. Monthly export prices of processed palm oil (Fob Usd/Tonne) [12].

|       | RBD PALM OIL | RBD P. OLEIN | RBD P. STEARIN | PFAD |
|-------|--------------|--------------|----------------|------|
| 2016  | 533          | 746          | 637            | 535  |
| 2017  | 746          | 637          | 535            | 729  |
| 2018  | 637          | 535          | 729            | 625  |
| JAN   | 535          | 729          | 625            | 694  |
| FEB   | 729          | 625          | 694            | 679  |
| MAR   | 625          | 535          | 694            | 679  |
| APR   | 694          | 535          | 679            | 679  |
| MAY   | 679          | 625          | 535            | 641  |
| JUN   | 641          | 625          | 535            | 603  |
| JUL   | 603          | 535          | 603            | 653  |
| AUG   | 653          | 603          | 535            | 645  |
| SEP   | 645          | 535          | 645            | 647  |
| OCT   | 647          | 535          | 647            | 554  |
| NOV   | 554          | 647          | 554            | 647  |
| DEC   | 647          | 554          | 647            | 549  |
| AVG   | 554          | 647          | 554            | 647  |

[12]
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