Techno-Economic Analysis Small Biodiesel Plant from Palm Sludge Oil

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Abstract. This research aims for the production of biodiesel (methyl ester) with the raw material of palm sludge oil (PSO) and perform a feasibility analysis through the parameters of Net Present Value, Internal Rate of Return (compare to bank interests rate), and Simple Payback Period on the small industrial scale 50-70 litters the biodiesel production obtained 91.30% yield from. Biodiesel can replace diesel oil as a fuel boiler for industrial use based on the quality parameters analysed, including methyl ester content, calorie value, flash point, viscosity and density. The economics analysis includes shows this business feasible to be applied.

1. Introduction

Every year around 25.360 tons of palm sludge oil (PSO) waste discarded into the environment [1]. PSO is a precipitate from the palm oil plant – waste disposal. It is contain several chemical compound such as Total Carbon 5.52%, Total Nitrogen 0.18%, Total Phosphorus 0.07%, Potassium 0.06%, COD 10082 mg L⁻¹ and BOD 7333 mg L⁻¹, TSS 7928 mg L⁻¹ and pH 6.1 [2]. The high numbers of COD can harm the fish and cause food chain contamination if discharged directly to the sewer without being treated first. Therefore, the best processing to the wastewater effluent has a high organic content by way of processing in anaerobic [3][4]. A variety of efforts to reduce the impact of environmental pollution, among others, with the utilization of palm sludge oil as animal feed ingredients performed by [5] through the fermentation technology.

The impact that appears due to the development of animal husbandry is the amount of greenhouse gases emissions which come from cattle farms. It is a significant contributor of Greenhouse Gas emissions in the form of fermentation enteric CH₄ 483.9 (Gg CO₂ e) and goats in the way of N₂O by 108,428 (Gg CO2e) in Central Sulawesi [6]. Instead of lowering the environmental impact, it increases the environmental impact of global warming, so it is necessary to think about the other forms of PSO processing into a way capable of reducing waste, and while lowering the Environmental impact pollution, namely the conversion of PSO to biodiesel (methyl Ester) biodiesel has a variety of advantages compared to petro diesel oil, both as a mixture within as well as pure fuel.

The advantages of biodiesel as fuel among others are manufactured from renewable raw materials, can be used in most diesel engines without modification. Biodiesel is more environmentally friendly
because it can be degraded in nature, non-toxic, high efficiency, small exhaust emissions, as well as low sulfur and aromatic content [7]. Production of biodiesel from Palm sludge Oil can produce as much as 93% yield as methyl ester [8] On a laboratory scale, but there has never been any research trying to discuss on the economics side and with a small industrial scale. It is necessary to study the technology applied economically to support the sustainability of a business. So, the feasibility of the ongoing business can be proven. The authors in this study aimed to determine the possibility of a small 50-70 litre factory-based enterprises producing biodiesel from Palm Sludge Oil. The biodiesel products used are not to be traded but used as supporting the internal operation of the factory, in fuel boiler replacing industrial diesel oil (High-Speed Diesel).

2. Methods

2.1. Conceptual design

![Figure 1. Route map of research](image)

2.2. Raw material

Palm Sludge Oil (PSO) obtained from distribution centre PT. Energy Feeds at the port of Tanjung Emas Semarang. Then raw materials were taken to the integrated laboratory of Diponegoro University where a biodiesel production machine with a capacity of 50-70 litters was installed. Before the production of biodiesel raw material is characterised to an analysis of Free Fatty acids (FFA) concentrations and water content

2.3. Biodiesel production

Based on figure 1, biodiesel production starts by analysed the FFA level, if the FFA level is higher than 2%, then the process should be esterified for the conversion of FFA to methyl ester instead. If the main component is FFA > 70% and the content of triglycerides (TG) is not more than 10%, then the process does not proceed to the Transesterification process instead.
2.3.1 Esterification. The material must be in the form of liquids to react to reactor biodiesel. PSO as much as 45500 gram put into a biodiesel vessel machine. A mixed solution consisting of methanol 14380 ml and H$_2$SO$_4$ 91 gram is slowly inserted while stirring 60 ± 2 °c, the reaction is carried out for 360 minutes [9].

2.3.2 Trans esterification. Esterification result or initial raw material if the level of FFA < 2% must be in the form of liquid first to be reacted to the vessel reactor biodiesel tank, PSO as much as 45500 g insert into the vessel of the biodiesel machine. A mixed solution consisting of methanol 14380 ml and NaOH 455 g is slowly added while stirring 60 ± 2 °c, the reaction is carried out for 120 minutes. It settled for 24 hours to get the separation between the layers of methyl ester and biodiesel correctly.

2.4. Biodiesel analysis

It analysed to obtain the quality, including methyl ester concentration by the MS GC method, calorie value using calorimeter Bomb, Flashpoint Open Cup method, viscosity and density.

2.5. Economic analysis

The data obtained from the above experiments conducted an economic analysis to calculate the parameters (Net Present Value, Internal Rate of Return, Return of Investment). In comparison to the profit or benefit are calculated on the difference in the price of industrial diesel oil.

2.5.1 NPV. NET Present Value (NPV) or net value is a comparison between PV net cash with PV investment over the lifetime of the investment. In this study used to calculate how many years of an investment expressed (positive) by comparing the cost of investment, operational costs with the benefits gained [10][11], using the following calculations:

$$NPV = \frac{Cost}{(1+i)^T}$$  (1)

I is the interest rate (%), and T is the n time of investment

2.5.2 IRR. The Internal rate of return (IRR) is an indicator of the efficiency rate of an investment plan acceptable. The amount of IRR is not directly determined and uses simulation to get the NPV value to zero. In this research, business feasibility compared with bank interest rates is applicable[11][12]. As for the calculation of IRR as follows:

$$IRR = I1 \times \frac{NPV_1}{NPV_1 - NPV_2} \cdot (I2 - I1)$$  (2)

NPV1 is NPV at an interest rate 1, NPV2 is NPV at an interest rate 2, IRR1 is interest rate 2 and IRR2 is interest rate 2.

3. Result and Discussion

3.1. Raw material

PSO raw material characterisation conducted by PT. Indonesian Energy Feeds as listed in table 1. Based on the results is the content of the FFA higher 70% (80.72%) Where there are no other components other than FFA such as triglycerides that can be converted into methyl esters. The next step is to conduct esterification reaction to transform FFA into Fatty Acid Methyl Ester (FAME). High levels of fatty acids consequence the consistency of the initial material is solid, and the initial process is heating above 40 °c to make the material liquid and can be made in the tank and the production process.
Table 1. PSO characterisation result

| No | Parameter                                | Result   |
|----|------------------------------------------|----------|
| 1  | Free Fatty Acid (As Palmitate acid)       | 80.72%   |
| 2  | Humidity                                 | 1.72%    |
| 3  | Insoluble impurities                     | 0.317%   |

3.2. Biodiesel production

Production of small industrial scale (40-50 kg) using the reactor owned by Diponegoro University with a capacity of 50-70 litters. The materials prepared are PSO 45500 g, methanol 14380 ml and H2SO4 91 g, the reaction carried out for 360 minutes at 60 ± 2 °C. The final result is 41.550 kg (50.424 litters) or 91.30% yield equivalent. Esterification was carried out using H2SO4 1% as a catalyst and the reaction for 360 minutes was able to lower the free fatty acid levels up to 83.7% [9]. 1:20 ethanol molar ratio and catalyst at 60 °C 300 rpm for 3 hours with an alum catalyst capable of lowering > 80% of free fatty acids [8]. Palm Oil Free Fatty Acid has performed esterification reaction to produce methyl ester, at reaction condition 1:11.6 molar ratio, 87 minutes stirring time and temperature 65 °C, SO42-/ZrO2 0.8% catalyst can provide 80.2% yield methyl ester [13].

3.3. Analysis

Biodiesel results are then carried out the study of the content of methyl ester, total glycerol, flash point, the calorie value of fuel, viscosity and density, from the result obtained values according to the table 2.
Table 2. Biodiesel PSO quality

| Parameter             | Biodiesel (PSO) | Biodiesel (Standard)[14] | Diesel Oil (Standard)[15] |
|-----------------------|-----------------|--------------------------|--------------------------|
| Calorie Number (cal/g)| 9316            | n/a                      | 10000                    |
| Flash Point Number    | 125             | Min 100                  | 60                       |
| (°C)                  |                 |                          |                          |
| FAME Concentration (%)| 68.05           | Min 96.5                 | n/a                      |
| Density (kg/m³)       | 824             | 850-890                  | 815-860                  |
| Viscosity (mm²/s)     | 2.6             | 2.3-6.0                  | 2.5-11                   |

Obtained calorie value Biodiesel PSO test results is 9,316 calorie/g. Compared to the calorie value of diesel oil and biodiesel or gas is considered lower, likely because there are still some impurities as on GC-MS chromatogram result (figure 4). When looking at the calorie value of coal 2,800-3,000 calorie/gram can still be used as a fuel boiler and done calculation of the needs in volume per day. Equality between the uses of 1 litter of diesel against PSO biodiesel can be calculated through the following formula (assuming technical boiler sheet as mention table 3) [16].

\[
q = \frac{Q \times (h_f - h_g)}{\eta \times LHV}
\]

Table 3. Boiler technical sheet

| Parameter                         | Specification                  |
|-----------------------------------|--------------------------------|
| Boiler Fuel                       | Diesel oil/biodiesel           |
| Number of steam (dry) output      | 10 TPH                         |
| Steam Pressure/Temperature        | 10 bar/180 °C                  |
| Boiler Efficiency                 | 80%                            |
| Diesel Oil Calorie                | 10,000 kcal/kg                 |
| Biodiesel Calorie                 | 9,316 kcal/kg                  |
| Enthalpy hg (10 bar saturated steam) | 665 kcal/kg                  |
| Enthalpy hf (feed water)          | 85 kcal/kg                     |

Based on calculations using formula (3) obtained the ratio of fuel consumption of biodiesel PSO and Diesel Oil is 1.07, meaning to produce the same heat as the combustion of 1 litre of diesel oil requires 1.07 litters of biodiesel PSO.

Figure 4. GC MS Chromatogram

Approximately 68.05% of free fatty acids are successfully converted to methyl esters from 80.72% of the free fatty acids listed in the certificate of analysis, which means that about 84.30% of free fatty acids are successfully lowered. Similar to [16] which is used as a reference for this reaction condition, able to decrease 83.7%. The esterification process was conducted using P-toluene sulfonic acid 0.75
wt%, 10:1 molar ratio, 60 ° and 60 minutes were able to convert 90.93% FFA to FAME [17]. Free fatty acid still can be found in results of the PSO biodiesel chromatogram. It comes in the form of oleic acid of 19.89%, and wherein subsequent studies can be modified temperature and reaction time, the addition of temperature and reaction time will increase the collision between molecules Thus increasing the number of substances that react [18]. Using the raw material waste cooking oil successfully convert into methyl ester as 82.54% [19].

The result of a flashpoint indicates that the number 119.5 °c means that the liquid will burn on the boiler burner at that temperature, using the temperature of the boiler lighter which reaches 3000 °C then the liquid will burn quickly. Components such as 12-Tricosanone, 1-Hexacosene and Ethanol, 2-(9-Octadecenyloxy) are long aliphatic chains that have a flashpoint > 150 °C This is likely to cause a larger flashpoint. As for the density, parameters obtained the value of 824 kg/m3 lower than the requirements specified by the standard biodiesel 850-890 kg/m3 while for viscosities obtained the amount of 2.6 mm2/s and still within the standard specification range Biodiesel 2.3-6.0 mm2/S. In the biodiesel PSO, there are still many impurities one of 12-tricosanone, 1-Hexacosene and Ethanol, 2-(9-octadecenyloxy) that need to be done optimisation for further purification.

3.4. Economic analysis

As a first step to the biodiesel production with a capacity of 50-70 litters needed some supporting equipment as listed in table 4.

| Item                | Price Per Unit | Total | Investment capital |
|---------------------|----------------|-------|--------------------|
| Biodiesel Reactor   | 100,000        | 1     | 100,000            |
| Water Pump          | 465            | 1     | 465                |
| Hose                | 20             | 20    | 400                |
| Plastic storage     | 30             | 20    | 600                |
| Plastic container   | 35             | 2     | 70                 |
| Bomb calorimeter    | 30,000         | 1     | 30,000             |
| Flash Point Analyser| 20,000         | 1     | 20,000             |
| Aluminium Pan       | 350            | 1     | 350                |
| Burner LPG          | 120            | 1     | 120                |

The first step of the feasibility assessment through NPV, IRR, and Simple Payback period should be calculated from benefit (added value) economically calculated from the difference in cost of good manufacturing or the cost of production and the cost of the existing fuel, so Obtained result as table 5.

| Cost Item            | Price   | Unit  | Amount | Total        |
|----------------------|---------|-------|--------|--------------|
| Raw Material         | Rp 56,472.00 | Kg    | 55.75  | Rp 5138.95   |
| H2SO4                | Rp 10,000.00 | liter | 14.4   | Rp 144,000.00|
| Water                | Rp 13,000.00 | m3    | 0.1    | Rp 13,000.00 |
| Bleaching Earth      | Rp 6,000.00 | Kg    | 2.78   | Rp 16,680.00 |
| Preparation          | Rp 11,250.00 | perhour | 1   | Rp 11,250.00 |
| Esterification       | Rp 11,250.00 | perhour | 6   | Rp 67,500.00 |
| purification         | Rp 11,250.00 | perhour | 1   | Rp 11,250.00 |
| Energy Cost          |          |       |        |              |
| Heating              | Rp 4,250.00 | Per M³ | 0.18  | Rp 765.00    |
| Esterification       | Rp 1,467.00 | Per KWH | 6   | Rp 8,802.00  |
| Depreciation         |          |       |        |              |
Table 6. NPV calculation

| Years | Cost       | Pv cost     | Saving   | PV1 saving | NPV1     |
|-------|------------|-------------|----------|------------|----------|
| 0     | Rp 152.005.000 | Rp 152.005.000 | Rp       | -          | Rp       |
| 1     | -          | -           | Rp 45.185.856 | Rp 42.628.166 | -Rp 109.376.834 |
| 2     | -          | -           | Rp 45.185.856 | Rp 40.215.251 | -Rp 69.161.583 |
| 3     | -          | -           | Rp 45.185.856 | Rp 37.938.916 | -Rp 31.222.667 |
| 4     | -          | -           | Rp 45.185.856 | Rp 35.791.430 | Rp 4.568.763   |
| 5     | -          | -           | Rp 45.185.856 | Rp 33.765.500 | Rp 38.334.263  |

The calculation shows the value of NPV > 0 or positive by the end of the 5th year for the replacement scenario of diesel oil to the PSO biodiesel so that the business for the production of biodiesel for HSD replacement is considered feasible based on NPV calculation with the investment scheme 5 Years. On the calculation scheme of IRR diesel oil to biodiesel is used data $I_1 = 12\%$ and $I_2 = 20\%$ per year, the data is obtained from the simulation results where $I_1$ limit where obtained positive NPV value and $I_2$ limit where the negative NPV value up to 5th-year investment. IRR calculation is shown as Table 7.

Table 7. IRR calculation

| Years | Cost       | Pv cost     | Saving   | PV2 saving | NPV2   | PV1 saving | NPVI     |
|-------|------------|-------------|----------|------------|--------|------------|----------|
| -     | 152005000  | 152.005.000 | -        | -          | -      | -          | -        |
| 1     | -          | -           | 45.185.856 | 37.654.880 | -      | -          | 114.350.120  |

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IRR PSO Biodiesel calculation is compared with HSD/solar fuel boilers as follows:

\[
IRR = 12\% + \left(\frac{10.879.898}{10.879.898 - (-16.871.630)}\right) \times (20\% - 12\%) = 18.78\% \tag{4}
\]

18.78% IRR retrieved when diesel oil is replaced with PSO biodiesel, so it becomes the feasible investment that uses the bank deposits (Bank Deposit interest 6%) [21]. The simple payback period for the application of this business scheme when replacing the solar HSD is for 3.36 years. Using the technology of supercritical and raw material waste cooking oil obtained simple payback period for 2.39 years and IRR 31.61% [23].

4. Conclusion

Process of biodiesel production using PSO with small factory-scale production machine obtained yield 91.30% or 50.42 litters. Profit scheme, when used as a substitute for solar HSD is Rp. 45,185,856. Investment parameters such as NPV > 0 with 5-year investment scheme, IRR > interest rate (6%) Bank Indonesia interest rate and simple Payback period for this scenario was obtained over 3.36 years of the return of capital.

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