Preliminary Plant Design of Biofuel From Algae in Balikpapan, East Kalimantan

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Abstract. Biodiesel is one of the promising alternative energy to replace fossil fuel which is produced from natural resources that contains lipid or oil. Common sources of biodiesel are lately growing controversy about the use of potential food sources for the production of fuel. One of the strongest non-food alternative for biodiesel source is algae since it can produce considerable amount of lipid based on their species and cultivation condition. One of the suitable species that can be used is Botryococcus braunii because of its ability to accumulate high amount of lipid and hydrocarbons extracellularly. All process simulations are done by using SuperPro Designer v9.0. The objective of this algae-based biodiesel preliminary plant design is to provide technological reviews, economical assessments, and HSE assessments of this plant. Based on supply consideration and process area needed, the best location for this plant is in Kariangau, Balikpapan, East Kalimantan with the estimated land area of 7,700 m². The value of IRR and ROI of this plant is found to be 17.39% and 16.9% respectively. The NPV of this plant is 2,902,358.32 USD. It can be concluded from the profitability analysis that this algae-based biodiesel plant with capacity of 3,000 ton of biodiesel per year is economically feasible with payback period of 5.91 years.

1. Introduction

For many years, fossil fuel has been considered as unclean and unsustainable source of energy. The use of fossil fuel is believed to be directly related to environmental degradation [1]. Based on the data of Indonesia’s oil production and consumption, the production of oil is decreasing while the consumption is increasing. It can be concluded that in the next few years, Indonesia is projected to face energy crisis. Thus government needs to try to shift the use of non-renewable energy to renewable energy such as biofuel [2].

To tackle the negative impact of fossil fuel and providing more sustainable source of energy, biodiesel has been considered as one of the strongest candidate to be used. Biodiesel can be obtained from vegetable oils or animal fats by transesterification reaction [3]. Since the energy demands are very high and continue to increase, the use of crops and other food-producing plants are feared to disturb the food supply [4]. To overcome this problem, it is essential to find another source for biodiesel production.

In recent years, algae have gain considerable interest as the potential feedstock for biodiesel and bioethanol production since they have around 20–80% oil contents [4]. Algae can produce 100,000 liters oil per hectare land used thus making it very potential as alternative source for biodiesel production [5].
The aim of this paper is to design a plant for high quality biodiesel production based on algae. In this process, *Botryococcus braunii* is used as feedstock. This species is used since it contains around 25-75% of oil and has the ability to accumulate lipids and hydrocarbons extracellularly [6][7].

2. Methods

For this plant design, there are few steps required to be done: process selection, process design, equipment sizing, hazard analysis, and economic analysis. For process selection, the process must be feasible in thermodynamics and kinetics study. The study needs to detail the whole main process of biodiesel production especially for the physical and chemical reaction process. At the design stage, this plant must begin with the concept of a process in the form of a block diagram. This is very crucial because it is the heart of the whole production process. Figure 1 illustrates the process of a block diagram process on an algae-based biodiesel plant that will be designed.

After ensuring the description of the production process, it is necessary to take into account all equipment and specifications which will be used for sizing space that are needed. It is important to take into account the costs that will be needed. It has been established that this algae-based biodiesel plant with a production capacity of 3,000 tons of biodiesel per year will be built in Kariangau, Balikpapan, East Kalimantan with the estimated land area of 7,700 m².

![Figure 1. Block flow diagram of algae-based biodiesel production.](image)

Furthermore, technical design can be established related to layout and the space needed for the production process with equipment known specifications, also with the production flow and plant safety analysis. With all information already having data that meets applicable standards, economic analysis of the continuity of plant operations can be given to the existence of this biodiesel algae-based plant in the future.

3. Results and Discussion

Based on the process chosen for the production, technical design of all the equipment can be made. There are a total of ten main processes of this plant to obtain biodiesel from algae which include...
preculture, algae cultivation, harvesting, drying, cell disruption, extraction, transesterification, purification, distillation, and washing.

Pre-culture is done to obtain algae inoculum. It takes place in shake flask and maintained at room temperature (28±2 °C), constant pH 7.5, and 12:12 light/dark hour cycle in rotary shaker at 100 rpm for adequate oxygen supply. The culture is harvested after 3 weeks of incubation and then transferred for cultivation. Cultivation is done in outdoor closed photobioreactor using POME 20% v/v medium, micronutrient (urea and NaHCO₃), and water. Closed PBRs is chosen since it provides higher biomass productivities compared to open ponds [8]. To obtain maximum biomass yield, algae is harvested after 3 weeks of cultivation. Harvesting process is done in batches using disc stack centrifuge with 6 batches each day for 7 days. This method provides 4,000 to 10,000 greater force so microalgae can be separated from its medium reliably. Drying process aims to remove the remaining intracellular water from algae. It is done by thermal drying in a drying drum. Algae is then inserted to drum as internal fins lining the inner wall of dryer passing hot gas stream. Cell disruption process is done to release as much lipid contained in algae. In this process, mechanical method using ball mill is applied. Cells are disrupted by collision with metal beads in ball mill. Extraction process aims to extract lipid from disrupted algae. Hexane is added to dilute lipid, the mixture is then centrifuged in a disc stack centrifugator at 6000 rpm for around 5 minutes. The lipid obtained from extraction has to be separated from hexane before entering transesterification process. The separation of lipid and hexane is carried out by distillation at 85°C. Transesterification aims to produce alkyl esters which are the main constituent component of biodiesel. This process is done by reacting triglycerides and alcohol using KOH as base catalyst. The product of transesterification contains alkyl esters, methanol, and KOH. This mixture are purified to obtain pure alkyl esters in a disc stack centrifugator at 6,000 rpm for 5 minutes. The remaining methanol is separated from alkyl esters by distillation. The boiler temperature is set at 102.44°C and distillate temperature at 64.44°C with the input temperature is estimated to be 80.56°C. To obtain biodiesel with high purity, the product of distillation is cleaned by dry washing to remove the remaining KOH. In this process, magnesium silicate powder is used to neutralize KOH.

| Table 1. Technical specification of main production equipment. |
|---------------------------------------------------------------|
| **Equipment** | Mass Rate (kg/batch) | Temperature °C | Pressure (kPa) | Volume (m³) | Diameter (m) | Height (m) |
| Mixing tank | - | 30 | 360 | 745.4 | 7.8 | 15.6 |
| Seed photobioreactor | 19.9 | 33 | 101.3 | 8.3 | 1.7 | 10.1 |
| Main photobioreactor PBR | 505,893 | 33 | 101.3 | 210.8 | 4.9 | 29.7 |
| Harvesting tank | - | 30 | 115 | 133.8 | 4.4 | 8.8 |
| Disc Stack Centrifugation | 22,224 kg/h | 33 | 101.3 | 0.03 | 0.2 | 1 |
| Rotary Dryer | 617.4 kg/h | 140 | - | - | 2.6 | 4 |
| Ball Mill | - | 33 | 101.3 | 1.4 | 1.2 | 1.2 |
| Mix Settler Column | - | 30 | 101.3 | 3.02 | 1.2 | 2.6 |
| Distillation Column 1 | 1,784.2 | 100 (boiler) | 101.3 | 2.8 | 1.1 | 2.8 |
| | | 45 (condenser) | | | | |
| Transesterification Reactor | 2,651.5 | 33 | 101.3 | 3.3 | 1.8 | 2.6 |
| Adsorber Column | 177,761.1 | 150 | 100 | 123.8 | 4.3 | 7.3 |
| Mixing Tank for Dry Washing | 2,143.2 | 30 | 101.3 | 2.9 | 0.8 | 2.7 |
| Filter tank | 2,164.6 | 60 | 70 | 18.9 | 2.4 | 4.2 |

In this research, 13 main equipment are chosen for whole process which include mixing tank, seed photobioreactor, main photobioreactor, harvesting tank, disc stack centrifugator, rotary dryer, ball mill, mix settler column, distillation column, transesterification reactor, adsorber column, mixing tank for dry washing, and filter tank. The specifications are calculated using SuperPro Designer v9.0 as used in several preliminary design of plant research [9][10]. The result is presented in Table 1 above. Total factory area planned for this plant is about 7,700 m² with total process area of 1,807.19 m². The factory layout and its process area distribution can be seen in Figure 2 below.
For utility of the plant, steam and water requirement are calculated. Steam is used for distillation process. To calculate steam requirement of the plant, all the needs of steam in each distillation column are summed based on the simulation done in SuperPro and multiply it by 1.3 for safety reason and leaking prevention. The amount of steam needed for this plant is 40.05 kg/batch for start-up and 4.01 kg/batch for make-up after recycling and condensation. In this process, water is also used for cooling. Cooling water requirement is calculated by summing up the amount of water needed for condensation in two distillation process and cooling process obtained from simulation data. By considering drift loss and water loss from blow down, the need of cooling water is found to be 4.78 kg/batch. Water is also needed for algae growth medium. Based on data from simulation, amount of water needed for medium is 123,970 kg/batch.

The water usage in the plant is divided into two types of usage which are process usage and domestic usage. The process water usage is calculated from the amount of water needed for steam generation, cooling down, and cultivation process. The amount of water needed for process is 124,334 kg/batch or 44,786,623 kg/year. Meanwhile the domestic usage of water is calculated from the usage of water from drinking water and toilet with the assumption of 20 workers. Therefore, the total usage of domestic water is 673,200 kg/year.

Electricity requirement is also calculated using the data obtained from the simulation. The amount of electricity needed for this plant is 499,275 kWh/day. For alternative energy source, this plant generates its own fuel using solar diesel that produce 1,732.888 kJ for every kilogram solar used. By assuming 30% electric supply disturbance happens annually, the plant is still considered efficient with productivity ratio of 12.91.

The health, safety, and environment management is done by assessing the hazard throughout the plan. Hazard Identification (HAZID) then the Hazard and Operability Study (HAZOP) have been done in this study to examine and formulate standard operational procedures (SOP). Emergency response plan and emergency operating procedures are also provided for emergency event as a mitigation and response to danger. One of it is evacuation plan where the detailed evacuation route can be seen in Figure 2. Waste treatment is another important aspect in this preliminary plant design. Treatment of waste water has been considered due to high value of BOD and COD and the presence of strong basic KOH from transesterification process.
The economic analysis of this plant is done by calculating capital expenditure (CAPEX) and operational expenditure (OPEX) which evaluated by profitability analysis using Chemical Engineering Plant Cost Index (CEPCI). CAPEX consists of total equipment cost, site development cost, building cost, off-site facilities cost, contingency cost, contractor fee, land, supporting facilities, additional cost, capitalized cost, and working capital. The calculation of total CAPEX is shown in Table 2 below.

| Component            | Cost (USD)  |
|----------------------|-------------|
| Equipment            | 4,043,557   |
| Site Development     | 404,356     |
| Building             | 808,710     |
| Offsite Facilities   | 202,178     |
| Contingency          | 606,354     |
| Contractor           | 121,307     |
| Land                 | 277,425     |
| Supporting Facilities| 135,925     |
| Additional           | 15,661      |
| Capitalized          | 133,705     |
| Working Capital      | 1,137,676   |
| **Total Capital**    | **7,887,035**|

The operational expenditure consists of equity, raw material cost, utility cost, labour cost, maintenance cost, insurance cost, distribution cost, marketing cost, and depreciation. The calculation of OPEX without equity, maintenance and depreciation can be seen in the Table 3 below.

| List of Expenditures      | Cost (USD) | Percentage (%) |
|---------------------------|------------|----------------|
| Raw material cost         | 298,849    | 33.20          |
| Direct labor cost         | 134,909    | 15.07          |
| Indirect labor salary     | 223,130    | 24.80          |
| Insurance cost            | 162,384    | 18.00          |
| Insurance & property tax  | 12,333     | 1.40           |
| Electricity cost           | 50,611     | 5.60           |
| Water utility cost         | 6,614      | 0.70           |
| Fuel utility cost          | 12,227     | 1.40           |
| **Total**                 | **901,058**| **100**        |

The calculation of income and cash flow is crucial to do profitability analysis. Income is determined by the money obtained by selling the product after tax and expenses have been deducted from the amount. Cash flow can be calculated by adding income decreased by outcome. The cumulative cash flow can be seen in Figure 3 below.
Based on the cash flow calculation, profitability of plant can be analyzed by calculating MARR, IRR, NPV, Payback Period, and ROR. The result of profitability analysis is shown in Table 4 below.

| Component       | Value               |
|-----------------|---------------------|
| MARR            | 15.9 %              |
| IRR             | 17.4 %              |
| NPV             | 2,902,358.32 USD    |
| Payback Period  | 5.9 years           |
| ROI             | 16.9 %              |

4. Conclusion

The production of biodiesel from algae can provide a solution for energy sustainability without disturbing food supply. This plant is very efficient in term of power usage with the productivity ratio of 12.91. The value of IRR and ROI from calculation is 17.39% and 16.9%. The NPV of this plant is 2,902,358.32 USD. It can be concluded from the profitability analysis that this algae-based biodiesel plant with capacity of 3,000 ton of biodiesel per year is economically feasible with payback period of 5.91 years.

5. References

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