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Selection of Harvesting Technology for Botryococcus braunii as Feedstock of Bio-crude Oil Production

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ABSTRACT

The continuous increase in energy consumption of fossil fuels has led to the urgency of research and development in the field of renewable energy for the future. Meanwhile, microalgae such as Botryococcus braunii are among the renewable energy alternatives and a third-generation source of bio-crude oil, producing more biomass compared to others. However, the challenges that are usually encountered in the selection of an effective approach for microalgae harvesting are the small size of cells (3-30 µm) and the similarity between their densities and growth media. Therefore, this research aims to determine the appropriate microalgae harvesting technology for bio-crude oil production using the Analytical Hierarchy Process (AHP). Several potential harvesting technologies that have been used include centrifugation, filtration, inorganic and organic flocculation, bioflocculation, electrocoagulation, and flocculation-sedimentation. The results showed that the parameters considered include energy need (0.339), cost (0.214), risk of contamination (0.098), efficiency (0.133), technology availability (0.066), microalgae strain flexibility (0.079), and production time (0.071). Subsequently, the pairwise comparison of seven alternatives and criteria for each harvesting technology are compared. Based on the results, flocculation-sedimentation with a weight of 0.202 is the best alternative that can be recommended as a microalgae harvesting technology

I. INTRODUCTION

Microalgae are potential feedstocks for producing sustainable biofuels and other high-value products [1]. This is because their derivation does not interfere with food availability since they are obtained from non-food raw materials. Microalgae are a third-generation biofuel source with several advantages over terrestrial crops due to their high potential yield and relatively quicker

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growth rates [2]. Generally, microalgae are a group of micro plants that belong to the algae class, with diameters between 3-30 µm, and single cells as well as colonies living in freshwater and marine areas. Photosynthesis is carried out in microalgae to produce biomass, which absorbs nutrients and carbon dioxide quicker than other crops. They also play a role in 1/3 of the carbon fixation process that occurs in the world and produces approximately 70% of the oxygen in the atmosphere [2]. Meanwhile, the species used in this research was Botryococcus braunii, which is a green colony freshwater microalga that produces hydrocarbons [3] and is present in all climatic zones except Antarctica [4]. The content of carbon, hydrogen, and the high heating value (HHV) in the biomass of Botryococcus braunii at approximately 32.9–54.7 MJ/kg have a higher value than other types of microalgae [5]. Previous reports have shown that harvesting is a significant challenge that occurs in the use of microalgae as renewable energy. This is due to the small size of micro-algal cells (3-30 µm), low concentration of < 0.6 g/L, and the similarity of the density of the algal cells to the growth medium [6]. Harvesting is carried out by separating microalgae from their growth medium using a solid-liquid separation technique to process the biomass and produce useful products. This process uses several methods, namely chemical, mechanical, biological, electrical-based operations, and a combination of these procedures. Meanwhile, an ideal method must be suitable for most of the microalgae types, achieve high biomass recovery, and use minimal energy with nominal operative cost [7]. Therefore, reducing the harvesting costs is important for the sustainable and inexpensive production of bio-crude oil.

Microalgae harvesting methods have advantages and disadvantages, which are distinguished by their efficiency, time and energy needs, investment, operational, and chemical costs. To achieve economically viable and sustainable production, the cost of these steps needs to be reduced [10]. Therefore, this research aims to select the most pre ferred harvesting technology for bio-crude oil production. The development of a systematic multi-criteria decision-making (MCDM) was carried out using Analytic Hierarchy Process (AHP) to evaluate the technology alternatives in microalgae harvesting. One of the strengths of AHP is combining both quantitative and qualitative information to identify the preferred alternative. The qualitative data are quantified through a survey from algal experts. In its development, AHP is used to determine the priority of choices with many criteria and as an alternative method to solve various problems [9].

II. METHODOLOGY

AHP has been widely applied and extensively investigated in several fields since its initial introduction by Thomas L. Saaty in 1980. In this research, the AHP method was used to determine the harvesting technology, which has a set of criteria to select the alternatives that were determined previously. It allows for bias in making decisions by combining logical considerations and values. Furthermore, its basic principle includes breaking the problem into separate elements, setting the priority of each component or aspect, and weighing the priority set logically and consistently [8]. The first step in the AHP method was to compile a hierarchy of research schemes at several levels. Level 1 was the purpose of this research, namely the appropriate microalgae harvesting technology. Level 2 was the 7 criteria used, which include energy need, cost, risk of contamination, efficiency, technology availability, microalgae strain flexibility, and production time, while level 3 was the alternatives to be selected. The alternative used consisted of centrifugation, cross-flow filtration, organic and inorganic flocculation, bioflocculation electrocoagulation, and flocculation-sedimentation. The objectives, criteria, and alternatives are shown in Figure 1.

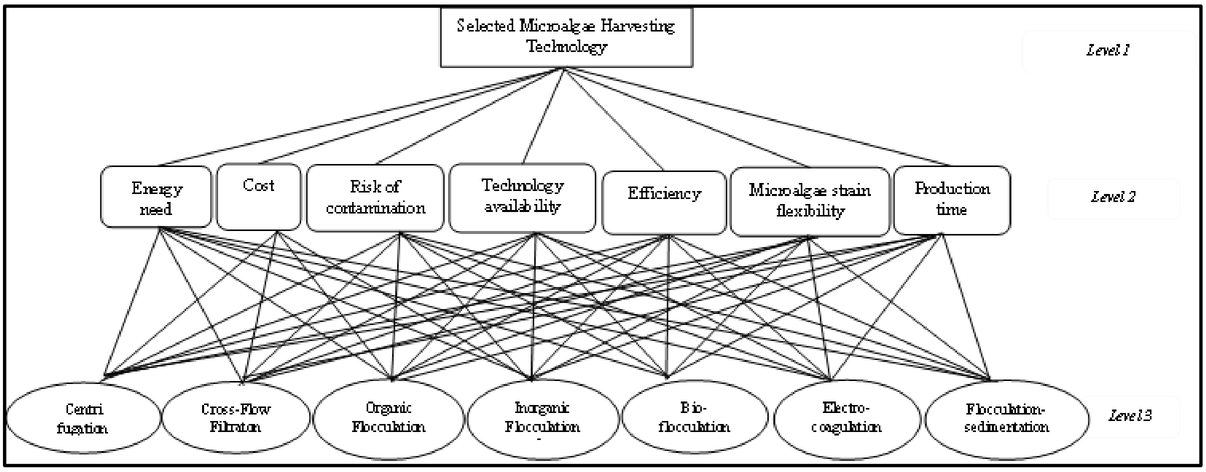

Figure 1. Analytic hierarchy process structure

The second step was to carry out pairwise comparisons between criteria and alternatives, which were scaled from 1 to 9 [9], as shown in Table 1. This was followed by the calculation of eigenvectors or the weight value of the criteria and consistency tests. The final stage was to calculate the weight value and arrange the priority sequence of each alternative.

Table 1. Hierarchy Rating Scale [6]

Interest	Variable definitions	Explanation
1	Just as important	The two elements have the same effect.
3	A little bit more important	Slightly siding with one of the elements
5	More important	Strongly siding with one element.
7	Very important	One element is very influential and its dominance is evident.
9	Absolutes are more important	One of the more essential elements of the partner is very clear.
2,4,6,8	The middle value of the assessment above	The value is given when there is doubt between the two options.
Reciprocal	When the ratio between the elements i and j yields one of the values above, the ratio between the elements j to i will produce the opposite value.	

III RESULTS AND DISCUSSION

An example of AHP is shown with the best microalgae harvesting technology (Figure 1). Based on previous research [10] – [13], there are several potential microalgae harvesting technologies, namely centrifugation, cross-flow filtration, organic and inorganic flocculation, bioflocculation, electrocoagulation, and flocculation-sedimentation

3.1 Criteria Weight Calculation (Level 2)

In this research, a pairwise comparison was carried out to indicate the preference for each criterion. The seven criteria compared were energy need, cost, risk of contamination, efficiency, technology availability, microalgae strain flexibility, and production time. The exact method was carried out by calculating the average of respondent data, followed by the consistency calculation as shown in Table 2.

Table 2. Pairwise comparison matrix for criteria

Criteria	Energy need	Cost	Risk of contamination	Efficiency	Technology availability	Microalgae strain flexibility	Production time
Energy need	1	3	3	5	4	3	3
Cost	1/3	1	4	4	2	3	2
Risk of contamination	1/3	1/4	1	3	1	1	1
Efficiency	1/5	1/4	1/3	1	1	1	1
Technology availability	1/4	1/2	1	1	1	4	3
Microalgae strain flexibility	1/3	1/3	1	1	1/4	1	2
Production time	1/3	1/2	1	1	1/3	1/2	1

The eigenvectors or the weight value of the criteria was calculated followed by consistency tests as shown in Table 3. Based on the calculations, the parameters that can be used as a basis for consideration in making decisions are energy need (0.339), followed by cost (0.214), efficiency (0.133), risk of contamination (0.098), microalgae strain flexibility (0.079), production time (0.071), and technology availability (0.066) as the last priority.

Table 3. Weight of criteria

Criteria	Energy need	Cost	Risk of contamination	Efficiency	Technology availability	Microalgae strain flexibility	Production time
Weight	0.339	0.214	0.098	0.066	0.133	0.079	0.071
Inconsistency				0.076			

3.2 Calculation of Alternative Local Weights Against Criteria (Level 3)

The calculation of the weight alternative against the criteria is also carried out to determine the best option for solving the problem. The value of the criteria for energy consumption, cost, efficiency, and production time is obtained from previous research [10]-[17], as shown in Table 4. Meanwhile, the criteria for risk of contamination, technology availability, and microalgae strain flexibility were obtained based on expert judgment. The qualitative decisions are scaled in pairs as shown in Table 1 by assessing the importance of an element compared to other components. The pairwise comparison from the assessment result of the three qualitative criteria is shown in Tables 5 to 7. The weighting result for this level is shown in Table 8.

Table 4. Determined matrix for microalgae harvesting techniques

Criteria	Energy need (kWh/m^3)	Cost (USD)	Efficiency (%)	Production time (min)
Centrifugation	5.50	500	90.0	10
Crossflow-filtration	2.06	200	92.5	10
Inorganic flocculation	4.00	300	95.0	40
Organic Flocculation	4.00	300	99.0	30
Bioflocculation	2.00	250	95.0	20
Electrocoagulation	3.00	400	90.0	20
Flocculation-sedimentation	2.50	250	99.0	25

Table 5. Pairwise comparison matrix for risk of contamination criteria

Risk of contamination	Centrifugation	Crossflow-filtration	Inorganic flocculation	Organic Flocculation	Bio flocculation	Electro-coagulation	Flocculation-sedimentation
Centrifugation	1	1/3	1	1/3	2	2	1/4
Crossflow-filtration	3	1	2	1/2	1/2	3	1/3
Inorganic flocculation	1	1/2	1	1/3	1	3	1/3
Organic Flocculation	3	2	3	1	2	4	1
Bioflocculation	1/2	2	1	1/2	1	2	1
Electro-coagulation	1/2	1/3	1/3	1/4	1/2	1	1/3
Flocculation-sedimentation	4	3	3	1	1	3	1

Table 6. Pairwise comparison matrix for technology availability criteria

Technology availability	Centrifugation	Crossflow-filtration	Inorganic flocculation	Organic Flocculation	Bio flocculation	Electro-coagulation	Flocculation-sedimentation
Centrifugation	1	3	2	2	3	3	1
Crossflow-filtration	1/3	1	1	1	1	2	1/3
Inorganic flocculation	1/2	1	1	3	3	3	1
Organic Flocculation	1/2	1	1/3	1	3	3	2
Bioflocculation	1/3	1	1/3	1/3	1	1	1/3
Electro-coagulation	1/3	1/2	1/3	1/3	1	1	1/3
Flocculation-sedimentation	1	3	1	1/2	3	3	1

Table 7. Pairwise comparison matrix for microalgae strain flexibility criteria

Microalgae strain flexibility	Centrifugation	Crossflow-filtration	Inorganic flocculation	Organic Flocculation	Bio flocculation	Electro-coagulation	Flocculation-sedimentation
Centrifugation	1	3	1/2	2	3	3	1/2
Crossflow-filtration	1/3	1	1/3	1/3	1	2	1/3
Inorganic flocculation	2	3	1	2	3	3	2
Organic Flocculation	1/2	3	1/2	1	3	3	2
Bioflocculation	1/3	1	1/3	1/3	1	2	1/3
Electro-coagulation	1/3	1/2	1/3	1/3	1/2	1	1/3

Microalgae strain flexibility	Centrifugation	Crossflow-filtration	Inorganic flocculation	Organic Flocculation	Bio flocculation	Electro-coagulation	Flocculation-sedimentation
Flocculation-sedimentation	2	3	1/2	1/2	3	3	1

Table 8. Calculation of weights between alternatives to criteria

Criteria	Energy need	Cost	Risk of contamination	Efficiency	Technology availability	Microalgae strain flexibility	Production time
Centrifugation	0.061	0.079	0.099	0.241	0.032	0.182	0.257
Crossflow-filtration	0.207	0.217	0.138	0.104	0.032	0.070	0.166
Inorganic flocculation	0.108	0.136	0.094	0.192	0.155	0.261	0.074
Organic Flocculation	0.108	0.136	0.239	0.158	0.297	0.182	0.105
Bioflocculation	0.189	0.167	0.134	0.065	0.155	0.070	0.133
Electro-coagulation	0.121	0.113	0.051	0.058	0.032	0.053	0.133
Flocculation-sedimentation	0.207	0.151	0.246	0.183	0.297	0.182	0.133
CR	0.007	0.015	0.073	0.061	0.001	0.049	0.014

As shown in Table 8, the calculation of the weights alternatives against criteria was carried out according to AHP. For every alternative, the value from Table 8 was multiplied by the individual criterion weight as indicated in Table 3. The sum of these products was the scores for each alternative and the highest score was selected as the best.

The Centrifugation score is calculated as follows:

$$(0.339 \times 0.061) + (0.214 \times 0.079) + (0.098 \times 0.099) + (0.066 \times 0.241) + (0.133 \times 0.032) + (0.079 \times 0.182) + (0.071 \times 0.257) = 0.100$$

The score for other alternatives is shown in Table 9. The results showed that flocculation-sedimentation is the most preferred harvesting technology followed by organic flocculation, crossflow filtration, bioflocculation, inorganic flocculation, centrifugation, and electrocoagulation.

Table 9. Weighting and ranking of harvesting alternatives

Alternative	Weight	Ranking
Flocculation-sedimentation	0.202	1
Organic Flocculation	0.161	2
Crossflow-filtration	0.158	3
Bioflocculation	0.153	4
Inorganic flocculation	0.134	5
Centrifugation	0.100	6
Electro-coagulation	0.092	7

IV. CONCLUSION

A multi-criteria decision-making model using the AHP approach was developed to evaluate seven harvesting technology, namely centrifugation, filtration, inorganic and organic flocculation, bioflocculation, electrocoagulation, and flocculation-sedimentation. Based on the data analysis, it was discovered that the level of influence of the criteria to be considered include energy needs (0.339), cost (0.214), risk of contamination (0.098), efficiency (0.133), technology availability (0.066), microalgae strain flexibility (0.079), and production time (0.071). The result showed that flocculation-sedimentation is the most preferred harvesting technology with a weight of 0.202, followed by organic flocculation, crossflow filtration, bioflocculation, inorganic flocculation, centrifugation, and electrocoagulation with 0.161, 0.100, 0.158, 0.153, 0.134, 0.100, and 0.092, respectively.

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