Analysis and design of expert system for microalgae production to produce biofuel

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Abstract. Microalgae are third-generation (3G) biomass sources to produce biofuel. The microalgae process to produce bio-oil consist of several activities such as cultivation, dewatering, and extraction. The cultivation of microalgae mainly using the Open Raceway Pond (ORP) with paddlewheel operation. The dewatering process using the centrifugation and drum filtration reduced the concentration of microalgae slurry to 20%. Furthermore, hydrothermal liquefaction (HTL) was used to extract to the bio-crude. Dissemination tools are needed to deliver knowledge of the microalgae production from cultivation to bioenergy In this research, the expert system was proposed to help the practitioner to apply the microalgae production. The methods used in this research consist of knowledge acquisition, knowledge representation, and development of the inference engine. The result of this study was the knowledge-based expert system for microalgae production. The expert system could help the practitioner in the preparation process of the microalgae cultivation.

1. Introduction
Microalgae are the potential biomass to produce food, feed, bioenergy, and another biorefinery product [1–4]. Microalgae are a single cell that grows with the photosynthetic reaction to converts the solar energy and nutrient to the biomass. The cultivation techniques of microalgae are the open pond and closed photobioreactors [5]. In the open system, mainly using the open raceway pond (ORP) with the paddlewheel. The CO₂, nutrient and solar energy are the primary resources of the microalgae cultivation [6].

Microalgae species selection is one of the critical activities in microalgae production. The microalgae species will become suitable for the specific growth rate and related to the environmental condition. Every microalgae species also has a specific content depend on the target product of microalgae. Microalgae suiteability in every cultivation technique are different. The characteristic of open cultivation are challenging to control the temperature and solar irradiance. In closed photobioreactor is high investment input and energy in operation. Another aspect, to evaluate the downstream process which are consist of dewatering and HTL extraction to crude oil.

The downstream process are conduct to process microalgae to valuable product. Microalgae harvested as a slurry (combination algae and water) using the dewatering technology such as centrifugation and drum filtration [7]. Extraction process to the biofuel using the Hydrothermal Liquefaction (HTL) or others technology [8]. Density of microalgae are fluctuated depending on the location, temperature, solar irradiance, nutrient, species, and cultivation method. In a large-scale area, the continuous or semi-continuous culture was applied to achieve continuous production. In semi-
continuous culture, algae harvested based on the Hydraulic Retention Time (HRT). The HRT condition such as 4, 7 or 14.

Delivering the microalgae knowledge to the users are the challenging. On of the method by developing the software to help user understand the cultivation techniques until processing to the bioenergy. Due to the complex combination and complex knowledge, expert system are essential to develop. In this research, expert system proposed to support the management of the microalgae to produce biofuel. Expert system consist of the knowledge based, inference engine and user interface.

2. Method

Expert system development was consist of several activities such as knowledge acquisition, knowledge representation, development inference engine, implementation, and testing (figure 1). The boundary of the research was evaluating the microalgae species for biofuel production. The main criteria were the oil (lipid) content and the growth of the microalgae.

![Figure 1. The Expert System Development Flow](image)

2.1. Knowledge Acquisition

Experts of microalgae selected from this research were researchers in Algae Biomass Energy System Development Research Center (ABES). ABES has been establishing from July 1, 2015 has many experienced in microalgae production from the laboratory scale to large pilot plant [9]. Members of ABES are expert and practitioner in microalgae production for a long time. They have the pilot plant in Minamisoma, Fukushima Prefecture Japan (figure 2). Knowledge acquisition conducted by joined in the discussion, visit the facility, and collected from a research paper. The knowledge acquisition defined the boundary of the cultivation of the microalgae to produce biofuel was Open Raceway Pond (ORP). The ORP selected due to the low energy and investment and easy to operate. However, the ORP has limitation such as easy to contaminate and difficult to control the culture condition.
2.2. Knowledge Representation

Knowledge representation techniques were used in this research was the tree structure. The tree-based was well-known knowledge representation techniques. Knowledge was consists of the activities of site selection, cultivation, dewatering and hydrothermal liquefaction of microalgae (figure 3). In the site selection part, the knowledge of a suitable location for the microalgae cultivation was evaluated. In many research, the temperature and solar irradiance were the critical factors in microalgae cultivation [10–13].

![Figure 3. The Content of Microalgae Expert System](image-url)
2.3. Inference Engine Development

Inference engine is the function to interact between the fuzzy membership function and rule-based. Inference engines calculated the result of the suitable microalgae based on the parameter from user input. Then, showing the information to the user by user interfaces.

2.4. Implementation

Expert system was implemented in the web-based application. PHP programming was used to develop the inference engine. The tacit knowledge from human expert and explicit knowledge from literature collected by the knowledge engineer. Then, the knowledge engineer decoded the knowledge and represented in the form that can stored in knowledge based. MySQL used to store the knowledge based with some technical modification. Then the inference engine implemented using the PHP programming. Users, able to access the expert system using the user interface that was developed by accessing the expert system. Figure 4 shown the general architecture of the system implementation of the expert system.

![Diagram of Expert System Architecture from Knowledge Acquisition to the User Interface](image)

**Figure 4.** Expert System Architecture from Knowledge Acquisition to the User Interface

2.5. Implementation

The final step of the expert system development was testing. The functionality testing conducted to evaluate the functionality of the system. Then, the validation of the evaluation system will determine to meet the requirement of users.
3. Result and Discussion

3.1. Knowledge Acquisition
In the knowledge acquisition process, knowledge was evaluated and captured from literature and visiting the facility of the microalgae. The main information and knowledge was captured consist of cultivation techniques, harvesting, dewatering and extraction to bio-oil. Cultivation microalgae are using open raceway pond (ORP), tube photobioreactor, and others techniques. The ORP are the most popular techniques for the energy production caused by the lowest cost and energy requirement. The harvesting technology applied such as membrane filtration, pressure filter, flocculation, centrifugation or dynamic settler. The harvesting, combined with the dewatering technology such as centrifugation, dynamic settler, membrane filtration, or others methods. The harvesting and dewatering can combined one or more technology in a process \[1,14]\.

The knowledge represented using the decision tree. The difficulties of knowledge acquisition was the knowledge distributed in the literature. To deal with this problem, the knowledge represented in the decision tree form. Then, the content of each knowledge breakdown based on the specific form of the expert system.

3.2. Knowledge Representation
The species selection using the specific growth rate (\(\mu_{\text{max}}\)) of the microalgae species, optimum temperature (\(T_{\text{opt}}\)), and Optimum Solar Irradiance (\(T_{\text{opt}}\)). Then, users can input the location of the microalgae will cultivate and the growth rate will evaluate using the equation (1-5).

\[
\frac{dc}{dt} = \mu \cdot c \\
C_2 = C_2 e^{\mu (t-t_i)} \\
\mu = \mu \cdot f(T) \cdot f(I) \\
f(T) = \frac{1}{T_{\text{opt}}} \cdot e^{1-(T/T_{\text{opt}})} \\
f(I) = \frac{1}{I_{\text{opt}}} \cdot e^{1-(I/I_{\text{opt}})}
\]

For the cultivation method, in this research focused on the Open raceway Pond Cultivation Techniques. The ORP cultivation using the semi-continuous culture with the HRT 4. The dewatering process using the default information from Minamisoma [15] as shown in figure 5. The concentration of Microalgae default from the ORP was 0.034 %, however this value will fluctuated depend on the cultivation condition. This value will be affected to the final yield of the microalgae from HTL process. This knowledge was included in this expert system.
3.3. Implementation

Expert system was developed and implemented in microalgae production. In this research, the knowledge content consist of the species selection, the cultivation of microalgae in Open Raceway Pond (ORP), dewatering and extraction process. The expert system was build to help the users to understand the activities of the microalgae cultivation. The system was implemented using the PHP and MySQL to store the knowledge based (figure 6).

Figure 5. The Flow Process of Microalgae to Produce Crude Oil
Figure 6. The Main User Inter of Expert System Microalgae

4. Conclusion and Future Work
The expert system was developed and implemented in the web-interface platform. The knowledge acquisition and knowledge representation were conducted from literature and practical application. In the future, the specific expert system for microalgae using wastewater such as Palm Oil Mill Effluent (POME) and manure was important to develop.

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