

Enhanced lipid extraction from microalgae in biodiesel production

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Abstract

In order to secure more effective lipid extraction method, this research investigated new lipid extraction method using laser with absorbent and sought its optimum operation control. In addition, this study compared lipid extraction efficiency and FAME conversion rate between laser extraction method at optimum condition and existing extraction method. Results from experiments for optimizing lipid extraction method using laser showed that the maximum extraction efficiency (81.8%) was attained when using laser with an output capacity of 75Wh/L. Extraction efficiency increased up to 90.8% when microwave treatment as pretreatment process was conducted. Addition of absorbents during lipid extraction process with laser showed higher extraction efficiency than laser and chemical method. It was also found that laser extraction method with absorbent had higher total fatty acid content (853.7 mg/g oil) in extracted lipid than chemical extraction method (825.4 mg/g oil). Furthermore, it had the highest FAME conversion rate (94.2%).

Keywords: biodiesel, microalgae, laser, lipid extraction.

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In the field of new renewable energy, development of alternative energy using biological resources has received great attention, especially biofuel production that includes bioethanol and biodiesel as alternative transport fuels. Although biodiesel produced through trans-esterification reaction has similar physical properties with petroleum-based diesel, it discharges less contaminant (e.g., particle matter) into atmosphere than conventional fossil fuel and reduces carbon dioxide emissions during cultivating oilseed crop [1]. In addition to the existing biodiesel production methods from animal and plant extracts, a newer method has been developed that utilizes vegetable oil extracts such as soybean and palm oil extracts. Documented evidence by Chisti [2] showed that gradual substitution of current transport fuels with biodiesel from vegetable oil extracts has adverse effects such as: destruction of ecosystem caused by farmland expansion (agricultural related activities); inflation of grain price by agflation; food scarcity and soil contamination by fertilizer. Therefore, current focus has been redirected on microalgae, characterized as third generation raw materials for biodiesel.

Biodiesel production using microalgae is an environmental friendly method which can biologically remove carbon dioxide by photosynthesis, which is the basic principle of the material circulation in the natural world

[3]. In addition, the process can be performed under very mild conditions at room temperature and atmospheric pressure, and produced biomass can also be utilized as a useful substance. The production process of biodiesel using microalgae is composed of cultivation of microalgae, harvesting biomass, lipid extraction process from algae and trans-esterification reaction of extracted oil [4]. Among the aforementioned production processes, lipid extraction process has been regarded as an obstacle to biodiesel production due to the high cost problems and low extraction rate [2]. Several methods such as expeller/press, solvent oil extraction, Soxhlet extraction, hydro-cracking, pyrolysis, liquefaction and hydrogenation have hitherto been used to extract lipid from microalgae [5]. However, these methods are not only economically inefficient, but also very slow. For example, chemical solvent extraction method, recognized as practically applicable method because of its relatively high extraction rate, requires pretreatment process such as drying and dewatering process of microalgae [6]. Thus, simple and effective extraction method for biodiesel from microalgae should be developed and the process can be reasonably efficient if lipid can be directly extracted from microalgae in slurry condition [7].

In this study, lipid extraction method using laser as an environmental friendly and economical method was developed in order to overcome limitations of chemical method. Existing chemical methods utilize highly volatile and toxic organic solvent which has low reutilization efficiency [8]. One of the advantages of extracting lipid using laser is that the process can be undertaken in slurry status thereby eliminating other miscellaneous processes. In addition, lipid extracted from microalgae is composed of triglyceride, chloro-

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phyll and carotene [9]. However, investigation conducted by Tautorus [9] showed that some components (chlorophyll and carotene) inhibit transesterification of triglyceride. Issariyakul and Dalai [10] proposed better method of removing such inhibitors using absorbents.

The objectives of this study were to obtain optimum operation control of lipid extraction method with laser by analyzing the effect of various factors. Effects of different pretreatment methods during lipid extraction were analyzed. Effect of laser's input power capacity was also analyzed. In addition, the effect of adding different absorbents in the slurry during lipid extraction and transesterification process were investigated. Finally, fatty acid methyl ester (FAME) conversion rate based on each method was investigated.

MATERIALS AND METHODS

Cultivation and harvest of microalgae

Scenedesmus sp. which has several advantages such as being less contaminated by other microorganisms and having a potential of propagation in the water containing high concentration of organic materials and heavy metals, was selected as target microalgae used for this research [11]. *Scenedesmus* sp. was isolated from an indoor raceway pond at Kyungpook National University in South Korea. In order to obtain enough biomass for the production of biodiesel based on microalgae, each seed culture was used to inoculate 16L of a commercial liquid fertilizer (1:500 dilution; 5.1% N, 10% P₂O₅ and 5% K₂O) in an 18 L transparent polycarbonate bottle and was autotrophically grown at 20 °C with a flow of air bubbles at rate of approximately 2 L/min under cool fluorescent lighting (approximately 70 μmol/(m² s)) with a light: dark cycle of 16:8 h. After incubating, biomass was harvested by centrifugation at 4615g for 10 min and stored at -70 °C.

Lipid content analysis of target microalgae

Overall lipid content was extracted from *Scenedesmus* sp. and estimated using modified method of Bligh and Dyer [12] to calculate the total lipid content. Lipids were extracted in the water bath at 65 °C for 1 h, after 60 ml Chloroform-methanol mixed solvent (2:1 volume ratio) was added into 1g of sample in the 250 ml round bottom flask. After the extraction was complete, it was washed 3 times using 5 ml of chloroform-methanol (2:1 volume ratio) with the filtration by using qualitative filter papers (Advantec, No.2) and then evaporated the solvent from extracted mixed solution in a water bath at 65 °C, and 25 ml of petroleum ether and 15 g of anhydrous sodium sulfate were added. Petroleum ether layer was separated by centrifugation at 3000g for 5 min, after shaking for a minute and then 10 ml of supernatant was dried at 105 °C for

30 min. The weight of the crude lipid obtained from samples was measured as follows:

$$\text{Total contents} = \frac{100(A-B)C}{D} \quad (1)$$

where *A* is the weight of extracted solution after the drying, *B* is the weight of the weighing bottle, *C* dilution rate and *D* dry weight of sample.

Cell disruption

Cell wall damaging of microalgae, as a pretreatment process for facilitating lipid extraction was necessary to improve extraction efficiency [13]. Thus, ultrasonication, microwave and grinding were selected as pretreatment for cell disruption and mutually compared in order to determine optimized pretreatment of lipid extraction method for this research. Ultrasonication and microwave treatment were respectively conducted for 10 and 5 min using 28 kHz sonicator (SH-1025, Saehan sonic, Korea) and 2450 MHz microwave oven (MW202LW, LG, Korea).

Lipid extraction method using laser

The laser extraction method used in this study was designed as shown in Figure 1. The type of laser used was 445nm blue laser with maximum output power of 2.5W (Working Voltage: DC 7.4 V, Beam Divergence: <1.2 mRad, Beam Diameter: <1.2 mm @ aperture).

Five lasers were installed along the perimeter of the irradiation tank. In order to maximize the reflectivity of laser, mirrors were installed inside the irradiation tank. After putting 1.4 L of prepared microalgae slurry into the irradiation tank, it was radiated by a set of five 2.5 W lasers to produce 25, 50, 75 and 100 W of overall energy consumption respectively.

Analysis of fatty acid profile and extraction efficiency

In this study, direct trans-esterification was applied to the analysis of the composition and content of fatty acid of lipid extracted from microalgae. After 10 mg of extracted lipid was put into the glass vial, 1 ml of heptadecanoic acid-chloroform solution (Sigma-Aldrich, 500 μg/L) as internal standard substance was added. And then 1 ml of methanol and 0.3 ml of sulfuric acid were added respectively. Prepared sample was agitated using vortex mixer (KMC-1300V) for 10 min and reacted at 100 °C for 10 min in constant-temperature water bath. After the sample was cool down at room temperature and blended with 1 ml of distilled water with vortexing for 5 min, 1 ml from the bottom of layer separated by centrifugation (4000g) was picked out using syringe. Fatty acid profile analysis of target microalgae was performed using gas chromatograph (Shimadzu Scientific Instruments, Columbia, MD, USA) equipped with a FID (Flame Ionization Detector) and HP

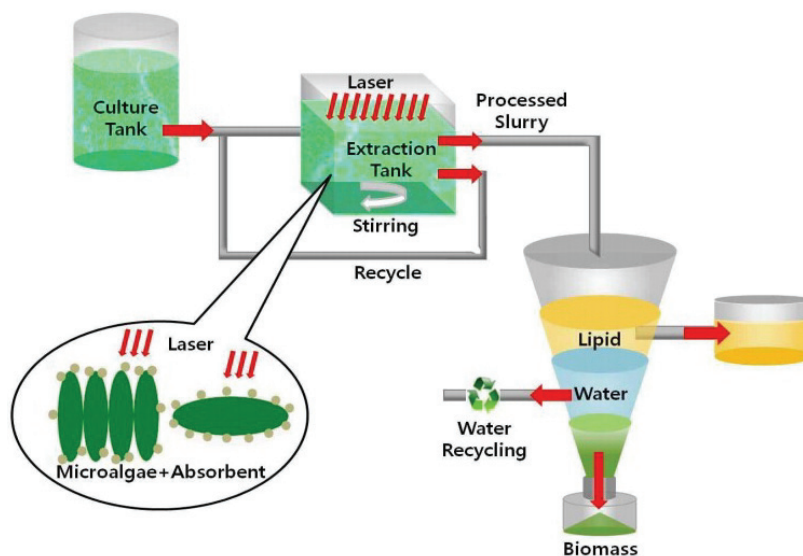


Figure 1. Process diagram of laser extraction method.

19091B-102 column (25 m×0.2 mm×0.33 μm). The composition was identified by comparing the retention times and fragmentation patterns with those for standards. Mix RM3, Mix RM5, GLC50 and GLC70 (Supelco) were used as the external standard substances. After analysis of fatty acid content (mg/g oil) of extracted lipid, fatty acid extraction efficiency was calculated as shown below:

$$\eta_F = 100\eta_L \frac{a}{1000} \quad (2)$$

where, η_F is fatty acid extraction efficiency (mass%), η_L is lipid extraction efficiency and a is fatty acid content in extracted lipid.

Biodiesel conversion reaction of extracted lipid

One of the limitations of esterification reaction is that it requires large amount of chemical catalyst for fatty acid methyl ester (FAME) production [14]. In this experiment, the effect of temperature and input amount of catalyst was investigated. Potassium hydroxide was selected as a base catalyst for trans-esterification and FAME was extracted from prepared fatty acid by using petroleum ether with water in separating funnel. After extraction process, it was washed with distilled water more than three times and petroleum ether was dewatered by anhydrous sodium sulfate. FAME was produced by transpiring and removing suitable amount of remained solution at a constant water bath temperature of 65 °C. Content of obtained FAME was analyzed using European Standard method EN 14103. To make an internal standard of 10 mg/ml concentration, *n*-heptane was filled to the marked line of 50 ml mess flask added with 500 mg of methyl heptadecanoate (C:17:0). Later, 250 ml of sample was mixed

with 5 ml of internal standard and analyzed by GC (Agilent 6890N). FAME contents of biodiesel derived from *Scenedesmus* sp. was calculated using equation below:

$$\text{FAME Content} = \frac{100 \sum A - A_{Ei} C_{Ei} V_{Ei}}{A_{Ei} m} \quad (3)$$

In the equation above, $\sum A$ – total area of the peak from C14:0 to C24:1, A_{Ei} – area of methyl heptadecanoate (ISTD), C_{Ei} – concentration (mg/ml) of methyl heptadecanoate (ISTD), V_{Ei} – volume of used methyl heptadecanoate (ISTD), m – the amount of sample analyzed.

Removal of free fatty acid

In general, trans-esterification refers to the process of producing FAME by adding the base catalyst to triglyceride and reacting with alcohol. However, it has been known that free fatty acid present during FAME conversion reaction using lipid extracted from microalgae is the source of saponification and leads to the reduction of reaction yield [15]. Hence, FFA content in raw material for biodiesel production should be converted or removed by esterification since they are impurities in the biodiesel conversion process and have an influence on acid value. The removal rate of FFA by the input amount of sulfuric acid, which was used as acid catalyst in the esterification process, was compared and analyzed. In general, FFA can be expressed as % content on the assumption that most oil and fat component are composed of oleic acid and it can be represented as a half of acid value. FFA content of lipid extracted from target microalgae was calculated from acid value obtained by neutralization method. To find acid value, the standard analysis method of EN ISO

661(animal and vegetable fats and oils – Preparation of test sample) was used. After melting fat by putting toluene and isopropyl alcohol at 1:1 ratio, two or three drops of 1% phenolphthalein solution was added. Later, it was measured by titrating with 0.1 M KOH until pink was kept for 30 s. The content of acid value and FFA was calculated using following formula proposed by American Oil Chemists Society [16].

$$\text{Acidic value} = \frac{56.11Vc}{m} \quad (4)$$

where V is the bulk solution of spent 0.1 M KOH, c represents molar concentration of KOH (M) and m represents the weight of sample.

RESULTS AND DISCUSSION

Total lipid content of *Scenedesmus* sp.

The main prerequisite to produce biodiesel with microalgae is that target microalgae has to contain plenty of lipid and it is also necessary to understand how much lipid content microalgae have. Hence, after disruption of cell wall by pretreatment, total lipid content in *Scenedesmus* sp. was analyzed through mixed solvent extraction method (Table 1). Results showed that lipid production capacity and content of *Scenedesmus* sp. as target microalgae was 9.5 mg/(L·day) and 133.2 mg/g of cell respectively and fatty acid content per cell in comparison with dry weight was 13.2±0.73 mass% (d.b.).

Table 1. Biomass production, total lipid content and productivity of *Scenedesmus* sp.

Item	Value
Dry weight, g/L	1
Biomass production, mg/(L·day)	71.4
Total Lipid content, mg/(g cell)	133.2
Lipid productivity, mg/(L·day)	9.5

Scenedesmus sp. used as a target microalgae in this study showed lower total lipid content (13.2±0.73 mass% (d.b.)) than the results reported by Kim *et al.* [17] on the lipid content of microalgae (average lipid content of 23% in green algae). This research proved that lipid content in microalgae tends to increase when microalgae is subjected to high environmental stress such as the lack of nutrients in culture medium [7]. Thus, it was considered that low lipid content of *Scenedesmus* sp. in this study could be due to the abundance of nutrient in culture which inhibits storage/accumulation of fats in the microalgae.

Fatty acid composition of *Scenedesmus* sp.

Fat produced by microalgae can be divided into neutral lipid (*e.g.*, triacylglycerol and cholesterol) and

polar lipid (*e.g.*, phospholipids and galactolipids). Triacylglycerol is usually used as main raw material for biodiesel production. In order to find out the content of triacylglycerol which can be converted into biodiesel, fatty acid composition of *Scenedesmus* sp. cultivated in this research was analyzed by GC.

Results of GC analysis of fatty acid composition showed that *Scenedesmus* sp. in this study had suitable composition of fatty acid (C14~C20) which is necessary for the biodiesel production and the order of main fatty acids was C18:2 > C16:2 > C16:0 (Table 2).

Table 2. Fatty acid contents and composition of lipids from of *Scenedesmus* sp.

Fatty acid	Abbreviation	mg/g cell	Content, %
Palmitic acid	(C16:0)	27.8	20.9
Palmitoleic acid	(C16:1)	1.6	1.2
Hexadecadienoic	(C16:2)	28.4	21.3
Stearic acid	(C18:0)	1.1	0.8
Oleic acid	(C18:1)	3.9	2.9
Linoleic acid	(C18:2)	52.7	39.6
α-Linoleic acid	(C18:3)	3.1	2.3
Arachidic acid	(C20:0)	1.1	0.8
Gondoic acid	(C20:1)	0.9	0.7
Erucic acid	(C22:1)	0.4	0.3
Others	–	12.2	9.2
Total	–	133.2	100

Composition of lipids from *Scenedesmus* sp. expressed as a percentage of total fatty acid content was 22.6% of saturated fatty acids and 68.2% of unsaturated fatty acids. This indicated that biodiesel produced from lipid extracted from *Scenedesmus* sp. had good flow property characteristics at low temperature and poor oxidation stability (Figure 2).

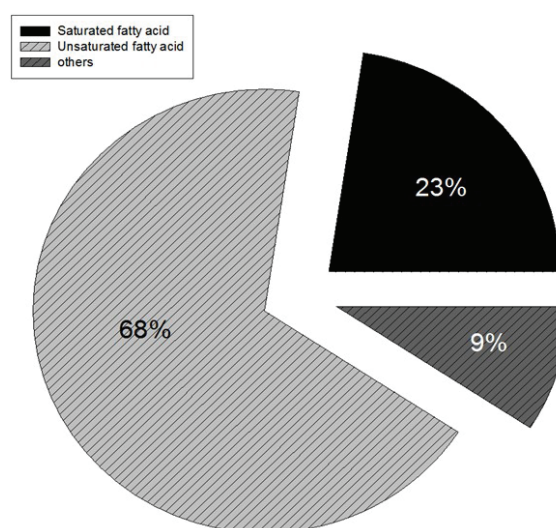


Figure 2. Comparison between saturated and unsaturated fatty acids in *Scenedesmus* sp.

Analysis of pre-treatment process

Ultrasonication and microwave are the most widely used methods for cell disruption because of their capacity to generate heat rapidly through amplification of vibration frequency for polar substances such as water for a shorter period of time [18]. However, in the absence of heating medium, the microalgae will burn if it is radiated by microwave. For this reason, existing methods such as chemical and Soxhlet lipid extraction are cumbersome in nature since they require additional processes such as pouring distilled water onto dried microalgae. This experiment was conducted under optimal operation condition of laser. From experimental results, it was identified that lipid extraction efficiency by each pre-treatment generally increased at least over 10% in accordance with an increasing extraction time (Table 3).

Table 3. Comparison of lipid extraction efficiency by different pretreatment methods

Pre-treatment	Parameter	Time, min		
		3	5	10
Grinding	Total lipid content mg/(g cell)	80	91	94
	Extraction efficiency, %	60.1	68.3	70.6
Ultrasonication	Total lipid content mg/(g cell)	108	118	121
	Extraction efficiency, %	81.1	88.6	90.8
Microwave	Total lipid content mg/(g cell)	91	105	109
	Extraction efficiency, %	68.3	78.8	81.8

Experimental results also showed that lipid extraction efficiency obtained using ultrasonication (90.8%) was higher than that of microwave and grinding for 10 min. From these results, we concluded that ultrasonication was suitable pre-treatment process for lipid extraction from *Scenedesmus* sp. using laser.

Optimization of lipid extraction process using laser

Lipid extraction yield and efficiency based on consumption energy according to the laser radiation were identified using five blue lasers with 2.5 W maximum output and 445 nm wavelength. In this study, extraction yield represented total amount of extracted lipid per 1g of microalgae and extraction efficiency indicated quantity of extracted lipid per total lipid content of microalgae in percentage terms. Extraction efficiency increased when the output Power of laser was increased up to 75 W. After that, the extraction efficiency decreased when the output power increased from 75 to 100 W. This indicated that there was either decomposition or oxidation of the lipid by laser. Results from experiments for optimizing lipid extraction method

using laser extraction method showed that the maximum extraction efficiency (81.8%) was attained when using laser with an output capacity of 75 Wh/L (Table 4).

Table 4. Comparison of extracted lipid amount, extraction yield, and efficiency by consumption energy

Parameter	Consumption energy (Irradiation time, h), W h/L			
	25 (2)	50 (4)	75 (6)	100 (8)
Extracted lipid amount mg/(g cell)	87	94	109	107
Extraction yield, %	8.7	9.4	10.9	10.7
Extraction efficiency, %	65.3	70.6	81.8	80.3

Effect of absorbent

This analysis was conducted with the aim of determining the effect of different absorbents at optimal operation conditions of laser. Lipid extraction efficiency was estimated based on input amount of each absorbent and consumption energy. Three materials were selected as target absorbent, namely: activated carbon, loess and clay. As shown in Table 5, it showed that at relatively low consumption energy (25 W h/L) lipid extraction efficiency with loess and clay decreased with an increase of input amount of respective absorbent. This was because the energy from laser was not sufficient enough to penetrate through the absorbent to the cell wall. At 50 W h/L, lipid extraction efficiency when loess and clay were used increased with an increase in input amount of absorbent (up to 0.5 g) and then decreased when the input amount was increased to 1 g. The same trend was observed at 75 and 100 W h/L. At consumption energy higher than 50 W h/L, lipid decomposition/oxidation could take place.

In contrast to previously mentioned absorbents, different trend in lipid extraction efficiency was exhibited by activated carbon. Although correlation between consumption energy and input amount of activated carbon could not be established, highest lipid extraction efficiency was obtained with input amount of 0.5 g and power consumption of 50 W h/L.

Analysis of total fatty acid content

Comparative analysis of Fatty acid content and fatty acid extraction efficiency between Soxhlet, laser and laser with absorbent extraction method was analyzed and results are shown in Table 6. The absorbent used in this analysis was activated carbon. Fatty acid extraction efficiency was calculated by multiplying total fatty acid content in lipid which was extracted through each extraction method by lipid extraction efficiency. Results indicated that extraction method using laser with absorbent had higher total fatty acid content (853.7 mg/g oil) in extracted fatty acid content than both

Soxhlet (825.4 mg/g oil) and laser extraction method (811.4 mg/g oil).

Table 5. Comparison of lipid extraction efficiency by type of absorbent used and consumption energy

Absorbent	Input amount g	Consumption energy, W h/L			
		25	50	75	100
Loess	0.3	63.8	90.8	85.6	67.6
	0.5	61.6	92.3	88.6	70.6
	1	57.8	90.8	87.1	60.8
Clay	0.3	65.3	90.2	89.3	70.6
	0.5	63.8	93.1	92.5	75.8
	1	59.3	91.6	87.8	64.8
Activated carbon	0.3	66.1	90.8	87.8	61.6
	0.5	67.6	93.8	89.3	60.1
	1	63.1	72.1	84.1	88.6

Table 6. Comparative analysis on fatty acid extraction efficiency and FAME conversion rate of three extraction methods

Extraction method	Total fatty acid content mg/(g oil)	Free fatty acid, %	Fatty acid extraction efficiency, %	FAME conversion rate, %
Laser	811.4	19.5	73.7	93.8
Laser with absorbent	853.7	19.1	80.1	94.2
Soxhlet	825.4	21.4	65.7	92.7

Total fatty acid extraction efficiency using laser with absorbent was also higher (80.1%) than both Soxhlet and laser method. This indicated that 19.9, 26.3 and 34.3% of overall ingredients in extracted lipid couldn't be converted to biodiesel by laser with absorbent, laser and Soxhlet method, respectively. Therefore, laser with absorbent extraction will show higher extraction efficiency in manufacturing biodiesel.

Comparison of FAME content by each extraction method

FAME content was analyzed based on reaction temperature and input amount of catalyst with the aim of determining optimal condition for transesterification. Result shown in Table 7 indicated that FAME content increased by increasing reaction temperature and catalyst input. In case of reaction temperature, the highest FAME content was obtained at 65 °C (83.5%). However, at 75 °C the amount of FAME content obtained decreased.

This was attributed to the fact that this temperature (75 °C) was higher than the boiling point of methanol which will lead to partial evaporation of methanol. This partial evaporation has negative effect on the catalyst:methanol ratio. Due to this reason, conversion rate of FAME content was reduced. Results from the amount of input catalyst showed that FAME content

increased with an increase in the input amount of catalyst for temperature. At 65 °C, the optimal input amount of catalyst was 1.5% which accounted for 94.2%.

Table 7. FAME content by input amount of catalyst and reaction temperature

Temperature, °C	Input, mass%		
	0.5	1	1.5
45	78.4	85.7	86.9
55	79.7	87.4	89.5
65	83.5	94.1	94.2
75	81.7	89.2	90.8

The aforementioned analysis was conducted based on different extraction methods. Table 6 showed comparison of free fatty acid and FAME contents of biodiesel using each extraction method. Experimental data showed that extraction method using laser with absorbent had higher FAME conversion rate (94.2%) than laser and Soxhlet extraction method. This was due to lower FFA content in extracted lipid when extraction process was conducted using laser with absorbent. Laser and Soxhlet extraction method had 19.5 and 21.4%, respectively.

It is considered that absorbent reduces acidic value of lipid since FFA among other components inhibits transesterification by causing saponification with base catalyst. Therefore, laser extraction method with absorbent could be considered as a suitable process for biodiesel production using microalgae.

CONCLUSIONS

In order to overcome problem of existing chemical extraction methods in biodiesel production using microalgae, more effective lipid extraction method with laser was developed and its optimum operation control was sought.

Experimental results indicated that lipid content in *Scenedesmus* sp. was below average because of the condition of the culture medium. It was concluded that lipid content tends to increase when microalgae is subjected to high stress environment culture. Lipid obtained after extraction contained suitable composition of fatty acid (C14~C20) which exhibited good flow properties at low temperature and poor oxidation stability.

It also revealed that all the pretreatment methods used for cell disruption showed an increase in lipid extraction over time under optimal operating conditions of the laser. Ultrasonication was the best pre-treatment method for lipid extraction with an overall extraction efficiency rate of 90.8%.

With regards to optimization of lipid extraction using laser, maximum lipid extraction efficiency (81.8%)

was achieved when the power output was increased up to 75 W. Further increase of power output resulted in decomposition or oxidation of lipid. Effect of absorbents on optimization of process showed that the highest lipid extraction efficiency was achieved when 0.5 g activated carbon was used when laser's energy consumption was 50 W h/L: this was attributed to the capacity of activated carbon to absorb compounds that inhibited trans-esterification process of triglyceride. FAME conversion rate for laser extraction method with absorbent was also higher than laser and Soxhlet extraction method because more fatty acid was extracted. Therefore, laser extraction method could be considered to be an effective method as compared with Soxhlet extraction method.

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IZVOD

POBOLJŠANA METODA EKSTRAKCIJE LIPIDA ZA PROIZVODNJU BIODIZELA IZ MIKROALGI Myung-Gyun Kim, Hyun-Wook Hwang, Antony Mutua Nzioka, Young-Ju Kim *Department of Environmental and Energy Engineering, Kyungpook National University, Daegu, South Korea* (Naučni rad)

Sa ciljem obezbeđivanja efikasnijih metoda ekstrakcije lipida, u ovom radu je ispitana i optimizovana kontrola rada nove metode ekstrakcije lipida primenom lasera sa apsorbentom. Pored toga, u ovom radu je upoređena efikasnost ekstrakcija lipida i FAME stepena konverzije laserskim postupkom ekstrakcije pri optimizovanim uslovima sa već postojećim postupkom ekstrakcije. Rezultati optimizacije ekstrakcije lipida laserskim postupkom su pokazali da je maksimalna efikasnost ekstrakciju (81,8%) postignuta kada se koristi laser izlaznog kapaciteta od 75 Wh/L. Efikasnost ekstrakcija je povećana do 90,8% kada je obavljen mikrotalasni predtretman. Dodavanjem apsorbenta tokom procesa ekstrakcije lipida sa laserom pokazana je veća efikasnost ekstrakcije u odnosu na lasersku i hemijsku metodu. Takođe je utvrđeno da postupak laserske ekstrakcije sa apsorbentom daje veći ukupni sadržaj masnih kiselina (853,7 mg/g ulja) u ekstraktu lipida u poređenju sa hemijskim postupkom ekstrakcije (825,4 mg/g ulja). Osim toga, ova metoda je imala najvišu stopu konverzije FAME (94,2%).

Ključne reči: