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Title(English)	Improving bio-oil yield in the hydrothermal liquefaction of microalgae and application of hydrochar as a low-cost adsorbent
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	環境理工学創造　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　学術　）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

This research aims to produce bio-oil from microalgae using hydrothermal liquefaction technology (HTL). HTL technology can treat wet biomass such as microalgae. In this technology, pressure and temperature are high, and therefore expensive in the industrial scale. On the other hand, at a low pressure and temperature, the bio-oil production yield is low. The purpose of this research is to increase the bio-oil production yield at a low pressure and temperature. For this purpose, catalysts and ultrasonic waves were applied to increase the conversion yield. The second objective of this study is to use hydrochar, which is a byproduct of the bio-oil production process, as a low-cost adsorbent. In this regard, microalgae hydrochar was used to remove heavy metals from wastewater. The contents of this thesis are as follows.

Chapter 1. Introduction
In this chapter, the basic background of the hydrothermal liquefaction of microalgae is introduced. The advantages of the biofuel production from microalgae as well as production technologies are reviewed. In addition, the characteristics of the bio-oil from microalgae are discussed. Finally, the objectives and the originality of this research are stated.

Chapter 2. Catalytic hydrothermal liquefaction of microalgae using heterogeneous catalysts
The objective of this chapter is to improve the bio-oil conversion yield by using heterogeneous catalysts. For this purpose, a nanocatalyst (nano-Ni/SiO_2), an acid catalyst (zeolite) and an alkali catalyst (Na_2CO_3) were used to increase the bio-oil yield at low temperatures (210°C, 230°C, 250°C). The major result of this work was higher bio-oil yields with the order of nano-Ni/SiO_2 > zeolite > Na_2CO_3 in the hydrothermal liquefaction of microalgae Nannochloprosis sp.. The highest bio-oil yield (30.0 wt%) was obtained at 250°C by using Nano-Ni/SiO_2. In the blank experiment, the elemental composition results showed that the oxygen content of the bio-oil decreased by increasing the temperature, and consequently its heating value increased by an increase of the temperature. On the other hand, the nitrogen content of the bio-oil increased with increasing the temperature. For the catalytic experiment, the oxygen and the nitrogen contents of the bio-oil for all types of catalyst were less than that of the blank experiment, and the heating value was higher for the bio-oil produced by the catalytic HTL. In addition, the results of this research also suggest the possibility of nanocatalyst recovery for 2-3 times.

Chapter 3. Ultrasonic-assisted hydrothermal liquefaction; enhancing bio-oil conversion yield and heating value
In this chapter, a new method was investigated in order to increase the bio-oil yield at a low pressure and temperature. The microalgae (Nannochloropsis sp.) were first pre-treated by ultrasonic waves for 30s, 60s, and 90s at 100W to make algal cell more fragile, and then bio-oil was produced using HTL at 210°C, 230°C and 250°C. The results depicted that using ultrasonic-assisted HTL (UHTL) could increase the bio-oil yield up to the maximum of 28.9% (90s sonication time at 250°C). Moreover, applying ultrasonic pre-treatment resulted in a decrease in the oxygen content of the bio-oil and consequently an increase in its heating value. It means that more thermal energy was produced using UHTL compared with HTL as a result of the higher bio-oil yield and heating value. However, using ultrasonic waves results in an increase in the total energy consumption of the process since it requires electrical energy. Therefore, the net energy was calculated to evaluate the effect of the sonication on the whole energy consumption. According to the results, the net energy was positive at all experimental conditions showing that UHTL increased the bio-oil production yield without a negative effect on the energy efficiency of the process.

Chapter 4. Characteristics and application of hydrochar as a low-cost adsorbent
In this study, hydrochar prepared from hydrothermal liquefaction of microalgae was characterized and investigated for the copper removal from aqueous solution. Two hydrochars were prepared at 210°C (HD210)

and 250°C (HD250). The effects of the initial solution pH, the initial Cu(II) concentration, the contact time and the temperature were investigated. Pore characteristic analysis revealed that the surface area of HD250 was higher than that of HD210 suggesting a higher potential for the adsorption process. FTIR analysis showed that hydrochars contained oxygen-containing functional groups on the surface which were effective for the copper removal. The adsorption experiment results indicated that the amount of the copper adsorption reached the maximum value at the solution pH of 5 which was considered as the optimum solution pH. In addition, HD250 had a higher amount of adsorption than that of HD210 at all values of the solution pH. The adsorption data at the optimum solution pH was well fitted by Langmuir's isotherm model and the adsorption process could be well described by the pseudo-2nd order kinetic model. Moreover, the thermodynamic analysis revealed that copper adsorption onto the hydrochar was an endothermic process.

Chapter 5. Conclusions
This chapter summarizes the important concluding remarks of this thesis.