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A STUDY OF BIODIESEL PRODUCTION FROM ALGAE

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Bachelor of Engineering with Honours
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A STUDY OF BIODIESEL PRODUCTION FROM ALGAE

RICKY STU ANDING

Thesis is submitted to

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To my beloved family, friends and the one who need it...

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ABSTRAK

Biodiesel merupakan bahan yang biosorot serta kurang dalam pengeluran gas CO_2 dan NO_X semasa pembakaran. Penggunaan minyak berasaskan petroleum kini dianggap sebagai sumber tenaga yang tidak kekal disebabkan sumber petroleum yang semakin berkurangan di samping menjadi punca utama pengeluaran gas CO_2 kepada persekitaran. Oleh sebab itu, sumber minyak baru yang mempunyai komposisi karbon yang neutral, sangat diperlukan untuk persekitaran dan bagi mengekalkan kestabilan economi. Biodiesel berasaskan hasil tanam-tanaman dan minyak terpakai berpotensi untuk dijadikan alternatif bagi petroleum tetapi ini tidak cukup untuk memenuhi permintaan bahan bakar kenderaan di dunia. Alga telah berkembang menjadi satu-satunya punca terbaik dalam penghasilan biodiesel. Adalah terbukti bahawa alga yang ditanam dengan persekitaran yang kaya dengan CO_2 boleh menghasilkan kandungan minyak yang banyak berbanding tumbuh-tumbuhan lain. Tumbuh-tumbuhan memerlukan matahari untuk pertumbuhan namun apa yang membezakan alga dengan tumbuh-tumbuhan ini ialah kandungan minyak yang dihasilkan oleh alga adalah jauh lebih banyak. Seperti yang telah dihuraikan di dalam projek ini, penghasilan sumber minyak dari alga cukup untuk menampung keperluan dan permintaan dunia terhadap bahan bakar kenderaan. Kajian yang dibuat ini adalah untuk mendapatkan proses transefikasi yang sesuai dalam penghasilan biodiesel dari alga, amaun biodiesel yang dihasilkan, sifat fizikalnya dan prestasi biodiesel ini di dalam enjin diesel sebenar. Dengan penggunaan biodiesel di dalam enjin diesel, hanya perubahan kecil dicatat untuk keputusan bagi brek kuasa kuda dan penggunaan minyak spesifik jika dibandingkan dengan minyak diesel biasa.

ABSTRACT

Biodiesel is a biodegradable fuel which produces lower CO_2 and NOx emissions. Continued use of petroleum sourced fuels is now widely recognized as unsustainable due to depleting supplies and the contribution of these fuels to the accumulation of carbon dioxide in the environment. Renewable and carbon neutral transport fuels are necessary for environmental and economic sustainability. Biodiesel derived from oil crops is a potential renewable and carbon neutral alternative to petroleum fuels. Unfortunately, biodiesel from oil crops, waste cooking oil and animal fat cannot realistically satisfy even a small fraction of the existing demand for transport fuels. Algae have emerged as one of the most promising sources for biodiesel production. Like plants, algae use sunlight to produce oils but they do so more efficiently than crop plants. Oil productivity of many algae greatly exceeds the oil productivity of the best producing oil crops. It can be inferred that algae grown in CO_2 with enriched air can be converted to oily substances. Such an approach can contribute to solve major problems of air pollution resulting from CO_2 evolution and future crisis due to a shortage of energy sources. As demonstrated here, algae appear to be the source of renewable biodiesel that is capable of meeting the global demand for transport fuels. This study was undertaken to know the proper transesterification process, amount of biodiesel production (ester), physical properties of algae biodiesel and algae biodiesel performance in a real diesel engine. With the used of biodiesel to replace normal diesel to run the diesel engine, there is a slight decrement in break horse power and a slight increment in the specific fuel consumption.

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°C	-	Degree Celsius
°F	-	Degree Fahrenheit
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
FKM	-	Fluorinated Elastomers
g	-	Gram
GHG	-	Green House Gas
h	-	Hour
Hg	-	Mercury
KOH	-	Potassium Hydroxide
l	-	Liter
MIDA	-	Malaysian Industrial Development Authority
min	-	Minutes
MJ	-	Mega Joule
ml	-	milliliter
NaOH	-	Natrium Peroxide
NO_2	-	Nitrogen Dioxide
NOx	-	Nitrogen Oxide
TPM	-	Technology Park Malaysia
US	-	United States
kN	-	Kilonewton

CHAPTER 1

INTRODUCTION

1.1 Background of Studies

The needs of energy are continuously increasing due to development in industrialization and population. The basic sources of these energy are petroleum, natural gas, coal, hydro and nuclear. The major disadvantage of using petroleum based fuels is the atmospheric pollution created by the use of petroleum diesel (ENS, 2008). Petroleum diesel combustion is a major source of greenhouse gas (GHG). Apart from the emission, petroleum diesel is also major source of other air contaminants including NOx, SOx, CO, particulate matter and volatile organic compounds (Cheah, 2007). Biomass is one of the better sources of energy. Large-scale introduction of biomass energy could contribute to sustainable development on several fronts; environmentally, socially and economically (PESWiki, 2008).

Biofuels are alternatives for petroleum-based fuels as they are produced from domestic renewable resources. Fuel ethanol is the most widely used biofuels for transportation applications. Second to ethanol is biodiesel, which can be used as a blend with gasoline up to 10% ethanol in any standard internal combustion engine, but above that, engine modification is needed (Cheah, 2007). Biodiesel is biodegradable, less CO_2 and NO_2 emissions. Continuous use of petroleum sourced fuels is now widely recognized as unsustainable because of depleting supplies and the contribution of these fuels to the accumulation of carbon dioxide in the environment (Hossain *et al.*, 2008). Renewable, carbon neutral, transport fuels are necessary for environmental and economic sustainability. Bioenergy is one of the most important components to mitigate greenhouse gas emissions and substitute of fossil fuels.

Biodiesel (monoalkyl esters) is one of such alternative fuel, which is obtained through transesterification of triglyceride oil with monohydric alcohols. It has been well-reported that biodiesel obtained from canola and soybean, palm, sunflower oil, algae oil as a diesel fuel substitute. Biodiesel is a nontoxic and biodegradable alternative fuel that is obtained from renewable sources. Biodiesel fuel can be prepared from waste cooking oil, such as palm, soybean, canola, rice bran, sunflower, coconut, corn oil, fish oil, chicken fat and algae which would partly decrease the dependency on petroleum-based fuel.

The burning of an enormous amount of fossil fuel has increased the CO_2 level in the atmosphere, causing global warming. Biomass has been focused as an alternative energy source, since it is a renewable resource and it fixes CO_2 in the atmosphere through photosynthesis (Cheah, 2007). If biomass is grown in a sustained way, its combustion has no impact on the CO_2 balance in the atmosphere, because the CO_2 emitted by the burning of biomass is offset by the CO_2 fixed by photosynthesis. Among biomass, algae usually have a higher photosynthetic efficiency than other biomass (Guiry, 2008). Algae are tiny biological factories that use photosynthesis to transform carbon dioxide and sunlight into energy so efficiently that they can double their weight several times a day (Briggs, 2004). As part of the photosynthesis process algae produce oil and can generate 15 times more oil per acre than other plants used for biofuels, such as corn and switchgrass (National Biodiesel Board, 2009). Algae can grow in salt water, freshwater or even contaminated water, at sea or in ponds and on land not suitable for food production. In fact algae are the highest yielding feedstock for biodiesel. It can produce up to 250 times the amount of oil per acre as soybeans (Hossain *et al.*, 2008).

Algae have emerged as one of the most promising sources especially for biodiesel production, for two main reasons (1) The yields of oil from algae are higher than those for traditional oilseeds, and (2) Algae can grow in places away from the farmlands & forests, thus minimising the damages caused to the food chain systems. As an advantage, Algae can be grown in sewages and next to power-plant smokestacks where they digest the pollutants and through this it can give us oil. Such an approach can contribute to solve major problems of air pollution resulting from CO_2 evolution and future crisis due to a shortage of energy sources. The tapping of engineered algae to produce bio-diesel and bio-ethanol has the best potential of great success because algae is very oily where it has about a 50% oil composition, it is the fastest growing organism and it becomes very dense enough to be harvested three times a day (Hossain *et al*, 2008). Though research into algae oil as a source for biodiesel is not new, the current oil crises and fast depleting fossil oil reserves have made it more imperative for organizations and countries to invest more time and efforts into research on suitable renewable feedstock such as algae (Wikipedia, 2008).

In fact, producing biodiesel from algae may be only the way to produce enough automotive fuel to replace current gasoline usage (Briggs, 2004). Algae produce 7 to 31 time greater oil than palm oil. It is very simple to extract oil from algae (ENS, 2008). On top of those advantages, algae can grow even better when fed extra carbon dioxide, the main greenhouse effect gas and organic material like sewage. If so, algae could produce biofuel while cleaning up other problems. Scientist nowadays are trying hard to determine exactly how promising algae biofuel production can be by tweaking the inputs of carbon dioxide and organic matter to increase algae oil yields.

1.1.1 Potential of Algae Biodiesel

Replacing all the transport fuel consumed in the United States with biodiesel will require 0.53 billion m^3 of biodiesel annually at the current rate of consumption (ENS, 2008). Oil crops, waste cooking oil and animal fat cannot realistically satisfy this demand. For example, meeting only half the existing U.S. transport fuel needs by biodiesel would require unsustainably large cultivation areas for major oil crops. This is demonstrated in Table 1 (Chisti, 2007). Using the average oil yield per hectare from various crops, the cropping area needed to meet 50% of the U.S. transport fuel needs is calculated in column 3 (Table 1.1). In column 4 (Table 1.1) this area is expressed as a percentage of the total cropping area of the United States. If oil palm, a high-yielding oil crop can be grown, 24% of the total cropland will need to be devoted to its cultivation to meet only 50% of the transport fuel needs (Chisti, 2007). Clearly, oil crops cannot significantly contribute to replacing petroleum derived liquid fuels in the foreseeable future. This scenario can be change dramatically, if microalgae are used to produce biodiesel. Between 1% and 3% of the total U.S. cropping area would be sufficient for producing algal biomass that satisfies 50% of the transport fuel needs (Table 1.1). The microalgae oil yields given in Table 1.1 are based on experimentally demonstrated biomass productivity in photobioreactors done by Yusuf Chisti, Institute of Technology and Engineering, Massey University, Palmerston North, New Zealand.

Table 1.1: Comparison of Some Sources of Biodiesel (Chisti, 2007)

Crop	Oil yield (L/ha)	Land area needed (M ha)[a]	Percent of existing US cropping area[a]
Corn	172	1540	846
Soybean	446	594	326
Canola	1190	223	122
Jatropha	1892	140	77
Coconut	2689	99	54
Oil palm	5950	45	24
Microalgae[b]	136900	2	1.1
Microalgae[c]	58700	4.5	2.5

Note: [a] For meeting 50% of all transport fuel needs of the United States.

[b] 70% oil (by weight) in biomass.

[c] 30% oil (by weight) in biomass.

Actual biodiesel yield per hectare is about 80% of the yield of the parent crop oil given in Table 1.1. In view of Table 1.1, microalgae appear to be the only source of biodiesel that has the potential to completely displace fossil diesel. Unlike other oil crops, microalgae grow extremely rapidly and many are exceedingly rich in oil. Microalgae commonly double their biomass within 24 h. Oil content in microalgae can exceed 80% by weight of dry biomass. Oil levels of 20–50% are quite common (Metting, 1996). Oil productivity, that is the mass of oil produced per unit volume of the algae broth per day, depends on the algal growth rate and the oil content of the biomass. Algae with high oil productivities are desired for producing biodiesel. Depending on species, algae produce many different kinds of lipids, hydrocarbons and other complex oils (Banerjee *et al.*, 2002). Not all algal oils are satisfactory for making biodiesel, but suitable oils occur commonly. Using algae to produce biodiesel will not compromise production of food, fodder and other products derived from crops. Potentially, instead of algae, oil producing heterotrophic microorganisms grown on a natural organic carbon source such as sugar, can be used to make biodiesel. However, heterotrophic production is not as efficient as using photosynthetic microalgae (Chisti, 2007) as the renewable organic carbon sources required for growing heterotrophic microorganisms are produced ultimately by photosynthesis, usually in crop plants. Production of algal oils requires an ability to inexpensively produce large quantities of oil-rich algae biomass (Cheah, 2007).

1.2 Global Status of Algae Biodiesel

The market for biodiesel is driven by the need for security of the energy supply and the recognition that greenhouse gas emissions are causing global warming. In the United States, the transportation sector is responsible for more than 70% of the petroleum consumed and one-third of the carbon dioxide emissions. Statistics are similar in Europe, where a Commission to the European Parliament put out a proposal to promote the use of biofuels for transport in November 2001, which introduced the objective of 20% substitution of alternative fuels in the road transport sector by the year 2020. The Commission issued the proposed directives in response to Kyoto Protocol emission reductions goals and to gain energy security for the members of the European Union (ENS, 2008).

Referring to the situation above, the need for renewable energy to replace fossil diesel oil has opened the opportunity towards many organization and private sectors to start doing research on algae biodiesel production. As an example, Aquaflow Bionomic based in Marlborough, United States announced that the company had produced its first sample of bio-diesel fuel from algae in sewage ponds. It is believed to be the world's first commercial production of biodiesel from algae outside the laboratory and the company expects to be producing at the rate of at least one million litres of the fuel each year from Blenheim by April 2007. According to Aquaflow Bionomic's spokesman Barrie Leay, algae-derived fuel has only been tested under controlled conditions with specially grown algae crops. Aquaflow's algae, however, were derived from excess pond discharge from the Marlborough District Council's sewage treatment works. Creating fuel from the algae removes the problem while producing useful clean water. The clean water can then be used for stock food, irrigation and, if treated properly, for human consumption (Briggs, 2004). Additionally, the process could also benefit dairy farmers and food processors as the algae also thrive in those industries' waste streams, unlike some bio-fuel sources which require crops to be specially grown which used more land, fuel, chemicals and fertilisers.

In another event, PetroSun, a diversify energy company specializing in the discovery and development of both traditional fossil fuels and renewable energy resources, has announced it has begun operation of its commercial algae-to-biofuels facility on April 1st, 2008. The facility, located in Rio Hondo, Texas, will produce an estimated 4.4 million US gallons equilibrium to 17 million litres of algal oil and 110 million pounds (50 million kg) of biomass per year off a series of saltwater ponds spanning 1,100 acres (4.5 km^2). Twenty acres will be reserved for the experimental production of a renewable JP8 jet-fuel. A feasibility study using marine microalgae in a photobioreactor is being done by The International Research Consortium on Continental Margins at the International University Bremen (PetroSun, 2008).

In November 8, 2006, Green Star Products announced it had signed an agreement with De Beers Fuel Limited of South Africa to build 90 biodiesel reactors with algae as raw material. Each of the biodiesel reactors will be capable of producing 10 million gallons of biodiesel each year for a total production capacity of 900,000,000 gallons per year when operating at full capacity, which is 4 times greater than the entire U.S. output in 2006. Also, GreenFuel Technologies Corporation has delivered a bioreactor to De Beers Fuel. In another event, Aquaflow

Bionomic Corporation of New Zealand announced that it has produced its first sample of home-grown biodiesel fuel with algae sourced from local sewerage ponds. Some open sewage ponds trial production has been done in Marlborough, New Zealand (Danielo, 2005).

For Asia region, the Department of Environmental Science at Ateneo de Manila University in the Philippines, is working on producing biofuel from algae, using a local species of algae. In Singapore, Pure Power said that it would establish corporate headquarters in Singapore for its renewable energy business. Pure Power recently acquired a stake in Aquaflow Bionomic, a New Zealand company which is harvesting wild microalgae and is supporting the Air New Zealand biodiesel trail scheduled for year 2008. Pure Power also acquired BioJoule Limited, a cellulosic ethanol concern. In a statement, management said that the International Energy Agency forecasts a 57 percent increase in energy needs by 2030, and that two-thirds would come from developing countries, led by China and India (Biofuel Digest, 2008).

As discussed earlier, algae biodiesel is not new. Research and developments have been done for the past few decades and nowadays the progression of it dramatically increased because of the need for renewable energy. Below shows some of the recent development of algae biodiesel production at certain region in the world (Biofuel Digest, 2008):

i. In the Netherlands, AlgaeLink announced a new process for extracting algae oil without using chemicals, drying or an oil press. The company said that its patent-pending technique uses 26 kilowatts of power to produce 12,000