Faculty of Engineering

Study of Coconut Biodiesel Transesterification Optimum Parameters to Investigate Diesel Engine Performance with Exhaust Gas Emission Analysis

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Biodiesel is one of the renewable alternative fuels, which can be obtained from vegetable oils or animal fats. Biodiesel's global demand has increased significantly over the last decade. The continuous rise in demand requires new technology to produce biodiesel in a more efficient and environmental way. Current biodiesel technology mainly produces biodiesel from crop oils that are commonly edible. Edible oil such as crude coconut oil (COCO) is used in this study. Titration method was performed to indicate crude coconut oil free fatty acid (FFA) value. FFA value of COCO determines which method of transesterification to be performed. This study focuses on acid/base catalysed transesterification using homogenous catalyst to produce biodiesel (fatty acid methyl ester) (FAME) from COCO. The optimum parameters of coconut biodiesel (CB) production were studied as well as the physicochemical properties, engine performance and emission analysis. Based on titration performed, FFA value was high with 14.82%. The optimum condition for producing coconut biodiesel were determined to be 0.01:1 v: v catalyst to oil ratio, 0.6:1 v: v methanol to oil ratio, with one hour reaction time at 55°C reaction temperature in acid catalysed esterification process. Whereas for base catalysed transesterification process, the optimum parameters were 0.015:1 w/w catalyst to oil ratio, 6:1 w/w methanol to oil ratio with two (2) hours reaction temperature at 60°C. The optimum condition of acid/base catalysed transesterification produces 98% of ester yield and 95% of biodiesel yield. The engine performance result shows that the engine power output and the mechanical efficiency dropped compared to conventional diesel. On the other hand, the specific fuel consumption increases with the increasing biodiesel blend. For emission analysis, the hydrocarbon and carbon monoxide decrease with the increasing biodiesel blend whereas the nitrogen oxides increased.

Keywords: Biodiesel, crude coconut oil, transesterification, engine performance.

Kajian Parameter Optimum Transesterifikasi Biodisel Kelapa Untuk Menyiasat Prestasi Enjin Diesel Dengan Analisis Pelepasan Gas Ekzos

ABSTRAK

Biodiesel adalah salah satu bahan api alternatif yang boleh diperbaharui, yang boleh diperolehi daripada minyak sayuran atau lemak haiwan. Permintaan global biodiesel telah meningkat dengan ketara sepanjang dekad yang lalu. Peningkatan permintaan yang berterusan memerlukan teknologi baharu untuk menghasilkan biodiesel dengan cara yang lebih cekap dan mesra alam. Teknologi biodiesel semasa terutamanya menghasilkan biodiesel daripada minyak tanaman yang lazimnya boleh dimakan. Minyak yang boleh dimakan seperti minyak kelapa mentah (COCO) digunakan dalam kajian ini. Kaedah pentitratan dilakukan untuk menentukan nilai asid lemak bebas (FFA) minyak kelapa mentah. Kajian ini memfokuskan kepada transesterifikasi bermangkin asid/alkali menggunakan mangkin homogen untuk menghasilkan biodiesel (asid lemak metil ester) (FAME) daripada COCO. Parameter optimum pengeluaran biodiesel kelapa (CB) telah dikaji serta sifat fizikokimia, prestasi enjin dan analisa pelepasan asap. Berdasarkan pentitratan yang dilakukan, nilai FFA adalah tinggi iaitu 14.82%. Keadaan optimum untuk menghasilkan biodiesel kelapa ditentukan ialah 0.01:1 v:v nisbah mangkin kepada minyak, 0.6:1 v/v nisbah metanol kepada minyak, dengan masa tindak balas satu jam pada suhu tindak balas 55°C dalam proses pengesteran bermangkin asid. Manakala bagi proses transesterifikasi bermangkin berasaskan, parameter optimum ialah 0.015:1 b/b nisbah pemangkin kepada minyak, 6:1 b/b nisbah metanol kepada minyak dengan dua (2) jam suhu tindak balas pada 60°C. Keadaan optimum transesterifikasi bermangkin asid/alkali menghasilkan 98% hasil ester dan 95% hasil biodiesel. Keputusan prestasi enjin menunjukkan bahawa kuasa pengeluaran enjin dan kecekapan mekanikal menurun *berbanding diesel konvensional. Sebaliknya, penggunaan bahan api khusus meningkat dengan peningkatan campuran biodiesel. Untuk analisis pelepasan, hidrokarbon dan karbon monoksida berkurangan dengan campuran biodiesel yang meningkat manakala nitrogen oksida meningkat.*

Kata kunci: *Biodiesel, minyak kelapa mentah, transesterifikasi, prestasi enjin.*

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LIST OF ABBREVIATIONS

AFR	Air Fuel Ratio
AI	Acid Index
ASTM	American Society for Testing and Materials
BHP	Brake Horse Power
BSFC	Break-Specific Fuel Consumption
$C_{20}H_{14}O_4$	Phenolphthalein
C_2H_5OH	Ethanol
$C_4H_{10}O$	Di-ethyl Ether
CB	Coconut Biodiesel
CDF	Commercial Diesel Fuel
CFPP	Cold Filter Plugging Point
CH_3OH	Methanol
CME	Coconut Methyl Ester
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COCO	Crude Coconut Oil

CP	Cloud Point
CRDI	Common Rail Direct Injection
CTO	Catalyst to Oil ratio
EN	European Standards
FAME	Fatty Acid Metyhl Esters
FCR	Fuel Consumption Rate
FFA	Free Fatty Acid
FT-IR	Fourier Transform Infrared
GHG	Greenhouse gas
H_2SO_4	Sulphuric Acid
HC	Hydrocarbon
HHV	High Heating Value
HV	Heating Value
IEA	International Energy agency
II	Iodine Index
KOH	Potassium Hydroxide
kPa	Kilopascal
kW	Kilowatt
LPM	Liter Per Minute
MTO	Methanol to Oil ratio

NaOH	Sodium Hydroxide
NO_X	Nitrogen Oxide
PD	Petrodiesel
PM	Particulate Matters
PP	Pour Point
RPM	Rounds Per Minute
RT1	Reaction time
RT2	Reaction temperature
SFC	Specific Fuel Consumption
SI	Saponification Index
SO_2	Sulphur Dioxide
WCO	Waste Cooking Oil

CHAPTER 1

INTRODUCTION

1.1 The Propitious of Biodiesel as an Alternative Fuel

The second most significant source of greenhouse gas emissions (GHG) is using fossil fuels in transportation (Espinoza et al., 2017). As a result, the automotive industry actively focuses on finding clean and renewable alternatives to fossil fuels (Veza et al., 2021a). As alternative and renewable energy sources, biofuels such as alcohol (Aditiya et al., 2019; Veza et al., 2020) and biodiesel (Silitonga et al., 2015) have gained appeal. The upward trend is anticipated to continue, with biofuels forecast to make up around 7% of road transportation in future years to come (Martinot et al., 2009).

Despite being a clean and renewable fuel, it is relatively has higher viscosities, around 11–17 times greater than those of gasoline and diesel, will result in several issues with fuel atomization, combustion, and pumping (Mahlia et al., 2020). Choking fuel injectors is another typical issue (Kumar et al., 2015). Additionally, biodiesel in an unmodified diesel engine could produce excessive engine wear (Dhar & Agarwal, 2014). As a result, it's critical to enhance the physicochemical characteristics of biodiesel to ensure compatibility with diesel engines (Veza et al., 2021b). It should be noted that modest adjustments can be needed to guarantee biodiesel compatibility with modern diesel engines.

It has good storage qualities like petroleum fuel and may be kept anywhere. Compared to traditional diesel fuel, handling, moving, and storing biodiesel has fewer chemical risks and hazards. Transesterification is used to make biodiesel from various feedstocks, including waste oil, non-edible oil, and edible oil. Diesel-biodiesel blends from vegetable oils burn more cleanly than regular diesel, producing less carbon, particulate matter, unburned and burned hydrocarbons (Teixeira et al., 2012).

Edible oil or animal fat interacts with an alcohol, such as methanol, in the presence of a catalyst that typically equates to a strongly basic, such as sodium or potassium hydroxide, to form biodiesel through the reversible transesterification reaction. Because of its higher physical and chemical similarities to diesel, transesterification is the best method for producing biodiesel (Farobie & Matsumura, 2017).

Coconut oil is one vegetable oil used as a raw material to make biodiesel. Coconut oil is inexpensive, has a high concentration of free fatty acids (FFA), and has few uses other than being consumed as food. In Asia, Central and South America, and some parts of Africa, coconut, a native of tropical eastern regions, is renowned for providing large yields per hectare. A coconut palm has a lifespan of 70 years, may produce up to 75 fruits annually, flourishes on nutrient-poor soil, and is simple to harvest (Santos, 2012). As a result, coconut oil has a great potential to lower the price of producing biodiesel.

Research by Bello et al. (2015) has shown that coconut diesel, produced through transesterification with methanol, has great potential as a biodiesel product. Similarly, studies conducted by Nakpong & Wootthikanokkhan (2010) and Chinnamma et al. (2015) have also demonstrated the promising potential of coconut diesel as a biodiesel. Globally, more than 350 oil-producing crops are currently being explored as potential sources of triglycerides for biodiesel production. The key to producing biodiesel is choosing an appropriate feedstock (Subbarayan et al., 2016). A viable feedstock should ideally satisfy industrial-scale production and low associated costs. The local weather, soil quality, topography, and farming practices used by the nation all impact how affordable and accessible the raw materials for biodiesel synthesis are. There is currently a market for biodiesel production from used cooking oil and animal fats, but choosing the suitable feedstock is crucial because it determines 70% of the cost of the finished product (Knothe, 2010).

This study investigates biodiesel synthesis from crude coconut oil (COCO), an edible oil. The base-catalyzed and acid/base-catalyzed transesterification processes created the coconut biodiesel (CB). To maximize the conversion of COCO into CB, the critical reaction parameters, including the oil to methanol volume ratio and catalyst concentration, were investigated. CB's physicochemical fuel qualities were examined utilizing tools constructed under EN and ASTM standards. Blends of CB and petrodiesel (PD) were used to investigate the performance of diesel engines.

1.2 Problem Statement

Biodiesel is a substitute fuel for diesel because it is non-toxic, biodegradable, eco-friendly, and renewable (Qiang Tan et al., 2012). Biodiesel has gained much attention from researchers worldwide because of its environmental impact and sustainability (Mofijur et al., 2013).

The use of biodiesel nowadays is very beneficial to the environment and the community. This is because the use of biodiesel will reduce the emission of carbon monoxide (CO), hydrocarbon, sulfur, polycyclic aromatic hydrocarbon (PAH), smoke, and noise in diesel engines compared with petrol diesel. However, the NO_x emission of biodiesel is higher than petrol diesel.

Table 1.1 shows the emission study of biodiesel blends of B20 and B100. From the result shown, consumption of blend B100 shows lower emissions compared to conventional diesel except for NO_x. Polycyclic aromatic hydrocarbon (PAH), identified as the root of cancer, shows a decrease of 80% in biodiesel emission (Mittelbach et al., 2004). Reduction of emissions from pure biodiesel positively impacts the environment, contributing to less global warming. Thus, without any doubt, biodiesel is better than petrol diesel.

Table 1.1 : Emission Comparison of Biodiesel and Diesel (Knothe, 2010)

AVERAGE BIODIESEL EMISSIONS COMPARED TO CONVENTIONAL DIESEL, ACCORDING TO EPA		
Emission Type	**B100**	**B20**
Regulated		
Total Unburned Hydrocarbons**	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
NOx	+10%	+2%
Non-Regulated		
Sulfates*	-100%	-20%
PAH (Polycyclic Aromatic Hydrocarbons)**	-80%	-13%
nPAH (nitrated PAH's)**	-90%	-50%***
Ozone potential of speciated HC	-50%	-10%

A monoalkyl ether known as biodiesel is created by transesterifying vegetable or animal fats. The current focus is on creating biofuel for transportation that can be produced economically without compromising the availability or demand for food. This is referred to as the second-generation feedstock for biodiesel made from edible oil.

The continuous research in production of biodiesel will aid in the reduction of environmental pollution and the advancement of socioeconomic conditions, particularly in underdeveloped nations (Lugo-Méndez et al., 2021). Edible oils include those from coconut, rapeseed, soybean, sunflower, and others. One of the edible crops with the potential to replace mineral diesel is the coconut, scientifically known as Cocos Nucifera. This is because coconuts are sustainable, readily available, and, most importantly, have lower feedstock market prices. However, despite its low cost and lack of practical secondary uses, coconut oil contains a high concentration of FFAs and is mainly used as a food product.

The use of coconut oil for energy generation, either in conjunction with or as a replacement for diesel, is receiving more and more attention (Hossain et al., 2012). Numerous incentives and subsidies have helped biofuels gain popularity in the United States and Europe, and several nations are already manufacturing them. It becomes more desirable to use edible oils as fuel as the price differential between petroleum and these fuels grows. The usage of biodiesel fuels based on vegetable oil has grown increasingly important from both an environmental and energy security perspective. Therefore, using coconut oil as a raw material has a significant potential for lowering the cost of producing biodiesel (Lugo-Méndez et al., 2021).

While the research on biodiesel, particularly from coconut oil as a feedstock, has shown promising results in terms of reduced emissions and sustainability, further studies are needed to optimize the production processes, investigate engine performance and emissions under various blend ratios, and assess the potential impact on food security and socioeconomic implications of large-scale coconut oil-based biodiesel production. Addressing these aspects will contribute to a more comprehensive understanding of biodiesel's viability as a renewable and environmentally friendly fuel alternative.

The research on biodiesel and its potential use of coconut oil as a feedstock has been driven by various significant factors. First and foremost, there is a growing concern about environmental issues, such as climate change and pollution, which has led to an urgent need for cleaner and more sustainable energy sources. Biodiesel, including coconut oil-based biodiesel, stands out as a greener alternative to conventional diesel, as it emits lower levels of harmful substances like carbon monoxide, hydrocarbons, sulfur, PAH, and smoke. Researchers are keen on exploring biodiesel's potential to reduce greenhouse gas emissions and its positive impact on the environment, particularly in the transportation sector.

The finite nature of fossil fuels and the quest for energy security have also been major drivers in biodiesel research. With a focus on renewable and sustainable alternatives, coconut oil, as a plant-based feedstock, holds promise in reducing our dependence on non-renewable fossil fuels. Additionally, the global demand for energy is increasing, necessitating cost-effective alternatives to traditional fuels. Biodiesel production from coconut oil and other edible oils presents an economically viable solution, especially in regions where coconut oil is abundant and easily accessible. Moreover, the pursuit of energy independence drives the exploration of locally available feedstocks like coconut oil for biodiesel production. Many nations seek to reduce their reliance on imported fossil fuels, and biodiesel from coconut oil aligns with this goal, contributing to greater energy self-sufficiency.

While previous research has highlighted the potential benefits of coconut oil-based biodiesel, there are areas that require further investigation. Researchers are actively seeking ways to optimize the production processes, aiming for higher yields and improved purity of biodiesel from coconut oil. Addressing the challenges related to the high free fatty acid content in coconut oil and finding efficient catalysts and process conditions are crucial aspects in this endeavor. Furthermore, in-depth studies on engine performance and emissions using coconut oil-based biodiesel blends, such as B20 and B100, are essential. Understanding the optimal blend ratios that lead to improved engine performance and reduced emissions is vital for promoting the widespread adoption of biodiesel.