MICROWAVE ENHANCED TRANSESTERIFICATION OF BIODIESEL FROM NON EDIBLE FEEDSTOCK USING WASTE MOLLUSC SHELLS AS HETEROGENEOUS CATALYST

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

School of Mechanical Engineering
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MARCH 2022

DEDICATION

Dedicated to my late parents, my husband, my beloved family and friends

ACKNOWLEDGEMENT

I wish to express my most profound appreciation to all those who helped m to complete this thesis in one way or another. First and foremost, I thank Allah Almighty, who provided me with strength and direction and showered my blessings throughout this journey. My sincerest gratitude to my supervisor, Associate Professor Dr Mohd Farid Muhamad Said and my former supervisor, Professor Dr Ir. Farid Nasir Hj. Ani for their continuous guidance and support. With their expert guidance and immense knowledge, I overcame all the obstacles that I encountered during the entirety of this process.

I also would like to thank Dr Nur Hamzah Said, my lab partner, for being there from the start. Not to forget all my co-supervisors, Associate Professor Dr Mohd Fadzli Abdollah and Dr Zulkarnain Abdul Latiff, thank you for their never-ending support. A special thanks go to my husband for his understanding and continuous support during my studies. All the help that I get formally or informally from Mr Mohd Latfi Che Haron (UTM), Dr Nurin Wahidah Mohd Zulkifli (Universiti of Malaya), my UM Lab mates, Mohd Nur Ashraf Mohd Yusoff and Syahir Amzar Zulkifli, Professor Noreffendy Tamaldin, and Mr Zuraini Zachariah from FTKMP, UTeM.

Saving the best for the last, I am deeply indebted to my late parents for their endless love and support throughout my life. I dedicated this work to my late parents, who have been my constant inspiration source. Not to forget, thank you to Universiti Teknikal Malaysia Melaka and the Ministry of Higher Education (MoHE) for providing the fund and scholar for me to complete this study.

ABSTRACT

Transesterification method is widely used to produce biodiesel at low volume production, which employs a homogenous catalyst and is found effective for processing virgin or highly refined vegetable oils. Hot plate and water bath are the common heat source methods being used to assist in expediting the reaction process. These methods are not only consumed time but they also wasted a lot of water for washing which makes the whole process less environmental friendly and costly. Microwave technology has been reported able to provide rapid heating but the report on its application in the transesterification process is somehow very limited especially involving the catalyst from mollusc shells. Until today, the waste mollusc shells application as the primary heterogeneous catalyst implemented in bulk size in converting high free fatty acid (FFA) feedstock into green and potential biodiesel with the microwave irradiation method is rarely reported. This research aimed to optimise biodiesel production and to identify significant parameters affecting the non-edible biodiesel yield via microwave-assisted transesterification. Waste mollusk shells oxides derived from Corbicula fluminea, Anadara granosa, and Perna viridis as heterogeneous catalysts were utilised to assist the microwave irradiation transesterification process. High FFA of rubber seed oil (RSO), and Jatropha Curcas oil (JCO) were employed as raw feedstock. The mollusc shells were sieved to different particles sizes ranging from 1 mm to 2 mm and were calcined at 900^{o}C for 4 hours at a 10^{o}C/min heating rate. Microwave power and reaction time were varied from 350 W to 450 W and 5 to 9 min respectively. The catalyst characterizations were carried out using X-ray diffraction (XRD), X-ray fluorescence (XRF), scanning electron microscope (SEM) and Brunauer- Emmett Teller (BET). A two-step transesterification process was utilised to perform the production. The acid esterification process used sulfuric acid and methanol to reduce the FFA percentage for RSO and JCO. The calcined catalysts mediated the transesterification reaction with feedstock and methanol via domestic microwave heating. Optimisation process was conducted using the Taguchi method of $L_{27}(3^5)$ orthogonal arrays. According to the analysis of the signal-to-noise ratio and ANOVA, the effect of catalyst loading was the most significant parameter with 45.1% and 47.5% contribution on the biodiesel yield from JCO and RSO, followed by the reaction time and molar ratio of methanol to oil. RSO biodiesel recorded the highest yield conversion of 96.6%, followed by JCO around 95.9% under the optimum parameter of 400 W microwave power and 7 minutes reaction time. It can be concluded that the calcium oxide catalyst derived from waste mollusc shells has a high potential to be used as biodiesel production catalysts in the transesterification of low quality feedstock that fulfill the ASTM D 6751 standard requirement.

ABSTRAK

Kaedah transesterifikasi digunakan secara meluas untuk menghasilkan biodiesel pada kadar pengeluaran yang rendah, dengan menggunakan pemangkin homogen dan ianya didapati berkesan untuk memproses minyak sayuran tulen atau yang ditapis halus. Plat panas dan kukusan air adalah kaedah sumber haba yang biasa digunakan untuk membantu mempercepatkan proses tindak balas. Kaedah ini bukan sahaja mengambil masa yang lama tetapi juga mengakibatkan pembaziran air yang banyak untuk mencuci yang menjadikan keseluruhan proses tidak mesra alam dan meningkatkan kos keseluruhan pemprosesan. Teknologi gelombang mikro dilaporkan mampu memberikan pemanasan yang cepat, namun laporan penggunaannya dalam proses transesterifikasi masih lagi sangat terhad terutamanya melibatkan pemangkin dari cengkerang. Sehingga hari ini, penggunaan sisa cengkerang pepejal sebagai pemangkin heterogen utama dalam saiz yang besar bagi tujuan menukar asid lemak bebas (FFA) yang tinggi kepada biodiesel yang berpotensi tinggi dan hijau dengan kaedah penyinaran gelombang mikro masih lagi jarang dilaporkan. Kajian ini bertujuan untuk mengoptimumkan proses pengeluaran biodiesel dan mengenal pasti parameter penting yang mempengaruhi penghasilan biodiesel melalui proses transesterifikasi dengan bantuan gelombang mikro. Sisa cengkerang pepejal oksida yang diperoleh daripada Corbicula fluminea, Anadara granosa dan Perna viridis digunakan untuk membantu proses transesterifikasi gelombang mikro ini. Minyak biji getah (RSO) dan minyak biji pokok jarak (JCO) dengan FFA yang tinggi digunakan sebagai sumber bahan bakar. Cengkerang diayak pada saiz 1 mm hingga 2 mm dan dikalsinasi pada suhu 900^{o}C selama 4 jam dengan kadar pemanasan relau 10^{o}C/min. Kuasa gelombang mikro dan masa tindak balas dipelbagaikan daripada 350 W sehingga 450 W dan 5 sehingga 9 minit. Pencirian pemangkin dijalankan dengan pembelauan sinar-X (XRD), pendarkilau sinar-X (XRF), mikroskop imbasan elekron (SEM) dan analisa Brunauer- Emmett Teller (BET). Kaedah dua-langkah transesterifikasi digunakan untuk produksi. Proses pengesteran asid menggunakan asid sulfurik dan metanol dilakukan untuk mengurangkan peratus FFA bagi RSO dan JCO. Proses transesterifikasi diteruskan dengan menggunakan kalsinasi pemangkin bersama metanol dan bahan mentah melalui pemanasan ketuhar gelombang mikro. Proses optimasi dijalankan menggunakan kaedah Taguchi $L_{27}(3^5)$ tatasusunan ortogon. Berdasarkan pada analisa nisbah isyarat-hingar dan ANOVA, kesan nisbah pemangkin adalah parameter paling penting dengan 45.1% dan 47.5% sumbangan pada hasil biodiesel dari JCO dan RSO diikuti oleh tindakbalas masa dan nisbah molar minyak ke metanol. Biodiesel RSO merekodkan penukaran hasil tertinggi dengan lebih 96.6% diikuti oleh JCO sekitar 95.9% pada parameter optimum kuasa gelombang mikro 400 W dan masa tindak balas 7 minit. Dapat disimpulkan bahawa pemangkin kalsium oksida yang diperolehi dari sisa cengkerang pepejal berpotensi tinggi untuk digunakan sebagai pemangkin pengeluaran biodiesel dalam transesterifikasi minyak mentah yang berkualiti rendah yang memenuhi keperluan piawaian ASTM D 6751.

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LIST OF ABBREVIATIONS

JCO	-	*Jatropha curcas* oil
ANOVA	-	Analysis of variance
AOCS	-	American Oil Chemist’s Society
ASTM	-	American Standard for Biodiesel Testing Material
AG	-	*Anadara Granosa* (cockle)
AV	-	Acid value
BET	-	Brunauer-Emmett-Teller
BSFC	-	Brake specific fuel consumption
BP	-	Brake power
BTE	-	Brake thermal efficiency
B10JCO	-	10% Biodiesel *Jatropha Curcas* Oil
B20JCO	-	20% Biodiesel *Jatropha Curcas* Oil
B10RSO	-	10% Biodiesel *Rubber Seed* Oil
B20RSO	-	20% Biodiesel *Rubber Seed* Oil
B100	-	100% Biodiesel
$CaCO_3$	-	Calcium Carbonate
CaO	-	Calcium oxide
CF	-	*Corbicula fluminea* (clam)
CN	-	Cetane number
CO	-	Carbon monoxide
DAG	-	Diacylglycerols
DIN	-	German Institute for Standardisation
DOE	-	Design of experiment
DOF	-	Degree of freedom
D2	-	Diesel Fuel
EDS	-	Energy Dispersive Spectra
EN	-	European Norm
EU	-	European Union
FFA	-	Free Fatty Acid
FAME	-	Fatty Acid Methyl Ester

GCMS - Gas Chromatography-Mass Spectroscopy
HC - Hydrocarbon
H_2SO_4 - Sulphuric acid
ISO - International Organization for Standardization
IUPAC - International Union of Pure and Applied Chemistry
IV - Iodine value
KOH - Potassium hydroxide
MAG - Monoacylglycerols
MeOH - Methanol
MS - Mean squares
MUFA - Mono-unsaturated fatty acid
NOx - Nitrogen Oxides
PV - *Perna viridis* (mussel)
PCR - Percentage Contribution Ratio
PUFA - Poly-unsaturated fatty acid
RSO - Rubber seed oil
SEM - Scanning Electron Microscope
SFA - Saturated fatty acid
SS - Sum of squares
SV - Saponification value
TAG - Triacylglycerols
TAN - Total Acid Number
TLC - Thin Layer Chromatography
UTM - Universiti Teknologi Malaysia
XRD - X-ray diffraction
XRF - X-ray fluorescence

LIST OF SYMBOLS

cSt - Centistokes

Å - Angstrom

m - Mass

p - Pressure

ρ - Density

v - Velocity

wt% - Weight percentage

g - Gram

α - Cut off for significance level

S_{BET} - BET surface area

S_f - Sum of the square of fth factor

S_T - Sum of the square of all parameters

% w/w - % weight per weight

% v/v - % volume per volume

R^2 - Coefficient of determination

P-value - Probability of occurrence

F-value - Fisher’s test

h - hour

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Energy is a vast topic and has become so vital for the well-being of humankind. However, energy production and use is the foremost source of greenhouse gas emissions, which intensify climate changes and cause biodiversity losses. Transportation has become an essential part of 21st-century society but has been marked as one of the contributors to climate change. The dependence on petroleum-derived fuels has caused the depleting of fossil fuel reserves and increased petroleum prices (Martins, Felgueiras, Smitkova and Caetano, 2019). That is where biodiesel comes in. Even though hybrids and hydrogen technologies have increased interest, these approaches require high capital costs and massive infrastructure investment. Thus, it is well worth considering an alternative fuel that can provide more technical advantages when compared with the existing conventional diesel fuel.

Biodiesel is one of the most promising alternative fuels having many advantages to overcome the environmental problem (D. Singh et al., 2020). It is well known as readily biodegradable and nontoxicity, and having a high cetane value offers improved ignition performance. It is also recognized as a high lubricity and low emissions fuel compared to diesel. Biodiesel can be mixed from ratios of B5 up to B100, where the number highlights the percentage of biodiesel in the mixture.

Biodiesel can be obtained from many renewable raw materials. The biodiesel feedstock can be classified into edible oils, non-edible oils, waste vegetable oils, microalgae, animal fats, and fat from insects. Biodiesel is defined as a mixture of mono-alkyl esters of long-chain fatty acids that are chemically derived from vegetable oils or animal fats through dilution, pyrolysis, transesterification and micro emulsification (Zahan and Kano, 2018). However, direct use of vegetable oils in a diesel engine is considered unsatisfactory and impractical. In addition, its high viscosity normally leads to operational problems in diesel engines such as filter clog, formation of deposits, and poor fuel injection that can reduce engine lifespan.

When selecting biodiesel as a substitute fuel, two main issues must be considered: the costs of raw feedstock and the biodiesel production process (Mansir et al., 2018). These two issues have made many industries and researchers have shifted to non-edible seeds for their potential biodiesel feedstock. In addition, the inexpensiveness of these 2nd generation feedstocks has recently engrossed a great deal of attraction. Some examples of non-edible oils that have been extensively reviewed are *Jatropha curcas*, *Calophyllum inophyllum*, *Sterculia foetida*, *Madhuca indica* (mahua), *Pongamia glabra* (Koroch seed), *Pongamia pinnata* (Karanja), *Hevea brasiliensis* (rubber seed), *Azadirachta indica* (neem), *Camelina sativa*, *Nicotiana tabacum* (tobacco), *Ricinus communis L.* (castor), *Simmondsia Chinensis* (jojoba), *Cerbera odollam* (sea mango), *Coriandrum sativum L.* (coriander) and many more.

Biodiesel has been widely produced worldwide and has grown steadily over the last decade. These projections are strongly affected by changes in policy packages, macroeconomic events and changes in crude oil prices. The first generation of biodiesel was largely produced from crops directly from the field, such as rapeseeds, cane, maize and palm. The 2nd generation biodiesel produced mostly from residuals and waste products was driven by support policies mainly developed by the United States (US) and the European Union (EU) due to the size of the two markets and their considerable biofuel imports. Palm oil and rubber seed oil have been reported as major biomass residues in Southeast Asia. At the same time, *Jatropha curcas* is an emerging non-edible feedstock as it can produce a high oil yield per hectare and grow in wastelands with a lifetime of up to 50 years.

As mentioned earlier, there are four typical modification processes to convert the raw feedstock or the triglycerides into biodiesel. Among those methods, transesterification is well-established due to catalyst recyclability, unreacted alcohol recovery, and capability to withstand higher free fatty acids (FFA) feedstock. These factors lead to more economical and higher quality biodiesel (R. Kumar and Pal, 2021). The transesterification process is carried out either with catalyst or non-catalyst. Base-catalysed transesterification, acid-catalyzed transesterification and lipase-catalyzed transesterification are common base catalyst types. Utilizing alcohols such as methanol at supercritical conditions is one example of a non-catalysed transesterification method (Gebremariam and Marchetti, 2017).

Recent studies have shown that the microwave irradiation technique is an economical, energy-efficient, and straightforward biodiesel method (Athar, Zaidi and Hassan, 2020; Nomanbhay and Ong, 2017). The incorporation of microwave technology has been widely recognized as one of the main instruments in food, biomass, pharmaceutical, constructions and many more. However, microwave applications at an industrial scale, especially in biodiesel production, are yet to be exploited. By scaling up, microwave biodiesel production has proven that this technology effectuates more exalted results over conventional methods.

Minimising the cost of biodiesel production by revamping and improving the production technology has attracted more interest amongst biodiesel industry players. Commonly used catalysts are homogeneous catalysts, such as sodium hydroxide (NaOH), sodium methoxide ($NaOCH_3$), potassium hydroxide (KOH), potassium methoxide (CH_3OK), sulfuric acid (H_2SO_4) and hydrochloric acid (HCl). Most production processes require a high proportion of alcohol to oil molar ratio and a longer reaction time (Musa, 2016). The formation of soap is rapidly developed when dealing with these homogeneous type catalysts, and the life span of the equipment is reduced due to the corrosion issues when dealing with acid catalysts. Catalyst consumption, wastewater generation and issues with high temperature are some of the issues related to these catalysts.

Due to the issue that ensues from the homogeneous catalyst, heterogeneous catalysts, either base or acid, are viewed as promising candidates. Having higher catalytic activity, less toxicity, excellent tolerance to a high free fatty acids (FFA) content feedstock, ability to eliminate multiple purification steps, easier catalyst recovery and reusability, higher catalytic activity, and lower toxicity is the main advantages of opting for heterogeneous catalyst (Chen et al., 2016; Kouzu and Hidaka, 2012; Boey, Maniam and Hamid, 2011). Two main categories of heterogeneous catalysts are catalysts with basic and acid sites. Basic site catalysts examples are calcium oxide (CaO), magnesium oxide (MgO) and zinc oxide (ZnO). Meanwhile, catalysts with acidic sites are formed from homogeneous mineral acids, such as sulphuric acid and phosphoric acid (H_3PO_4), that become heterogeneous by supporting them in an inorganic oxide (silica, alumina or zirconia).

Calcium oxide is the most popular choice of heterogeneous base catalyst owing to several advantages: mild reaction condition, low production cost, higher reusability, very high catalytic activity, good tolerance for water and high FFA feedstock, easy step in purification and separation process resulting in high biodiesel yield production and purity (Kouzu and Hidaka, 2012; Widayat, Darmawan, Hadiyanto and Rosyid, 2017; Linggawati, 2016; Singh and Verma, 2019). The abundance of waste from natural sources, especially from calcium sources, such as shells, eggshells and bones, have significantly shown that these sources can be commercialised as a potential alternative catalyst and at the same time able to reduce the overall production cost. The reusability of the catalyst is reported can reach up to more than five times. In addition, the calcination temperature is critical in determining the reactivity of the CaO. These diversified technologies open the door for renewable catalyst development and simultaneous waste material recycling.

Several studies have reported using renewable CaO catalysts from different waste materials for edible and non-edible oil transesterification using the conventional heating system. According to Encinar et al. (2012), inefficient heat transfers and longer reaction times are often associated with the conventional transesterification method. On top of that, other issues that are often associated with the conventional transesterification method are excess quantity of reactants, high reaction temperature and stirring speed (Sharma, Kodgire and Kachhwaha, 2019). The traditional water wash method in conventional technique often contributed to the issue of glycerol separation. The visibility and potential market of the biodiesel industry is quite limited due to these factors.

Energy and time efficiencies are fundamental to green chemistry and engineering fields. Regarding this crucial issue, microwave irradiation has gained much attention over the last decade as an efficient heat transfer medium. Many researchers are attracted to microwave irradiation potential as an efficient biodiesel production method. Its advantages are lower energy consumption, less solvent use, higher yield, tolerance for water presence, lower waste generation, and slower reaction time (Lin and Chen, 2017; Buasri and Loryuenyong, 2017).

The microwave irradiation technique for biodiesel production is still limited to batch production since it is not easy to upscale the laboratory synthesis to industrial production. The number of research groups in biodiesel production that focus on microwave chemistry and technology is still limited, most probably because of no funding agency to support this research area (Kappe, 2019). Another issue for the low penetration depth of microwave radiation into absorbing materials depending on their dielectric properties. The most critical issue is the safety aspect that needs careful and extra attention to prevent injuries.

In response to these issues, this research was done to integrate technical aspects such as the design of experiments and optimization process validation via a statistical approach and establish an economic batch-transesterification microwave irradiation process. Furthermore, to reduce the production cost, some important variables are observed: catalyst loading, the molar ratio of methanol to oil, reaction time, microwave power input and type of catalyst used. This paves the path for developing microwave techniques for large-scale biodiesel production.

1.2 Problem Statement

Biodiesel is one of the most promising alternative fuels having many advantages to overcome the environmental problem. The utilization of biodiesel is predicted to increase by 60% by 2030, owing mostly to industrialisation, population growth, and higher living standards (Ogunkunle and Ahmed, 2019). However, the price of raw materials, their availability and the production process's cost are the major drawbacks that need to be considered when choosing biodiesel as an alternative. A 2nd generation biodiesel derived from non-edible sources is becoming recognised as one of the efforts to reduce the dependency on edible sources. Non-edible oil plants can easily thrive in arid and semi-arid conditions and grow in low soil fertility with good moisture. Due to the high level of toxins present in the plant, its oil is not safe for human consumption. Up to now, the rubber seed oil and *Jatropha curcas* oil have had no major application. These are the factors that drive the use of these non-edible oils as the primary raw materials for green and high yield biodiesel (Banković-Ilić, Stamenković and Veljković, 2012)

Current biodiesel productions are dominated by the transesterification process in the presence of catalysts via conventional technologies that are more suitable for processing virgin or highly refined vegetable oils. Catalyst selection is essentially depending on the FFA level in the raw oil. Although homogeneous catalysts dominate the biodiesel industry due to their simplicity, high yield production, and shorter reaction time, this method still faces several drawbacks, particularly in large scale production. High amounts of water required for the washing process, especially when dealing with high FFA content of oil feedstock, makes homogeneous type catalyst not environmentally friendly, and in the end, increases the overall cost production. In addition, the recovery and purification process such as glycerol recovery, removal of excess water, catalyst, impurities and contaminants are essential and need extra cost to produce high-quality biodiesel that meet all the standard requirements (Daud, Sheikh Abdullah, Abu Hasan and Yaakob, 2015).

In addition to the challenges mentioned above, the treatment for alkaline waste water is quite complex and need an extremely slow reaction at room temperature. According to Vicente, Martínez and Aracil (2004), two major contributors to the lower biodiesel yield in homogeneous transesterification production are the dissolution of the methyl ester in the glycerol phase and the formation of soap during the washing process. The complex and convoluted post-treatment process has limited the development of the large industrial-scale application of homogeneous catalysts (Chang et al.,2017; Fukuda, Kondo, and Noda, 2001).

Heterogeneous catalysts have emerged as an effective alternative catalyst for more sustainable biodiesel production (Roschat, Siritanon, Yoosuk, Sudyoadsuk and Promarak, 2017). Several advantages characterise heterogeneous catalysts in comparison to homogeneous catalysts. Some of the advantages that led to the reduction in overall biodiesel production cost are: eliminating the washing method, simple and straightforward separation process, faster reaction rate, low cost, environmentally friendly, recyclable catalyst, low level of toxicity, high catalytic activity and high FFA content tolerance (Amin, 2019).

For biodiesel production, heterogeneous base catalysts of metal oxides have been investigated (Refaat, 2011). These catalysts include alkali earth metal oxides (calcium oxides, CaO and barium oxide, BaO), mixed metal oxides (magnesium aluminium, MgAl), transition metal oxides (Iron (II) oxide, FeO) and supported metal oxides. Among various reported heterogeneous acidic and basic catalysts, naturally derived CaO based basic catalysts have been used extensively due to their easy availability and low cost (Zeljka Kesic, Lukic, Zdujic, Mojovic, & Skala, 2016).

Even though the implementation of the microwave technique is one of the best solutions for producing good and quality biodiesel that meet the emission standards, it is still considered few in the literature. Other issues are the low penetration depth of microwave radiation into the absorbing materials depending on their dielectric properties. Most notably is the safety aspect that needs careful and extra attention. Thus, there is an urgent requirement to replace the existing conventional methodologies with a new one that is more environmentally friendly, economically viable, and technically applicable and reduces the safety aspect involved in biodiesel production.

The current study is also intended to optimise important variables in the production process such as reaction time, the microwave power input, catalyst loading, ratio of methanol to oil, and the self-produced calcium oxide heterogeneous catalysts from waste biomass. Furthermore, a prospective new technology should handle non-edible and low-quality cheap feedstock with a minimum level of complexity.

1.3 Research Objectives

This research study sought to understand the biodiesel production of non-edible oils using the microwave irradiation method. The following goals are intended to be met by this research:

(a) To synthesize the heterogeneous catalyst morphological characteristics on various temperatures and calcination times.

(b) To produce biodiesel from rubber seed oil (RSO) and *Jatropha curcas* oil (JCO) non-edible oil feedstock using waste shells as catalysts via 2-step acid esterification and transesterification microwave irradiation method.

(c) To optimise the reaction variables; reaction time, microwave power input, methanol to oil molar ratio, catalyst concentration and type of catalyst used in producing a high and good quality non-edible oil biodiesel.

1.4 Scope of study

In achieving the objective of the research, important tasks need to be carried out comprising of four research scopes such as:

(a) Develop a comprehensive overview on the current build of batch microwave-assisted transesterification systems, inclusive of its process critically, constrain parameters and raw materials used to produce a high yield biodiesel production

(b) Produce heterogeneous calcium oxide catalysts from waste shells to enhance the conversion of non-edible oils to biodiesel. The catalytic activity of the produced catalysts was investigated using the catalyst characterization method (SEM-EDS, XRD, XRF and BET).

(c) Transesterification of non-edible oil (rubber seeds oil and Jatropha curcas seeds oil) was conducted using batch microwave irradiation system at different reaction times, catalyst concentration, molar ratio oil to methanol, microwave irradiation power and reaction temperature.

(d) Optimization by Taguchi method and biodiesel produced were subjected to comprehensive chemical and physical analysis that was measured according to ASTM D 6751 and EN 14214 standards.

1.5 Significant of study

This work provides a better understanding of the production of various samples of non-edible oils by batch microwave heating technique, which shows a promising biodiesel production with a short reaction time and a high yield of production. The result of the study could be used as a guide and contribution in promoting the microwave irradiation technique in a wide variety of biodiesel production since the reliability of the technique is more efficient and guaranteed. There is a need for further study on the building and designing a good, scalable and efficient microwave biodiesel production that can lead to highly efficient and cost-effective production. Furthermore, combined experimental and some modelling of efforts, the methods can be improved and provide useful physical insight and detailed quantitative information needed to optimise biodiesel production. The use of heterogeneous catalysts solely from the waste material is an alternative to the expensive commercial catalysts in the market and may provide a sustainable route for biodiesel production.

1.6 Organization of dissertation

This dissertation is made up of five chapters. The organization of the chapters is listed as follows:

Chapter 1 gives an overview of the research topic. It introduces the importance of energy, GHG emissions, climate change, increasing prices and expected depletion of fossil fuels, the importance of biofuels, and suggests biodiesel as a solution for the current world energy crisis. This is followed by a background that shows the importance of biodiesel and gives some examples of biodiesel feedstock worldwide and the possible methods to overcome the high viscosity and low volatility of vegetable oils in conventional diesel.

Chapter 2 gives a historical overview of global transportation sector energy consumption and emissions production trends followed by discussing biodiesel as an emerging energy resource, advantages and disadvantages of biodiesel, biodiesel feedstock, biodiesel extraction methods, biodiesel production technologies, biodiesel standards and characterization, properties and qualities of biodiesel and problems and potential solutions of using straight vegetable oils.

Chapter 3 explains in detail the research methodology and design.

Chapter 4 is dedicated to showing all the results obtained from the experimental work and presenting the study's findings, followed by a detailed discussion and analysis of these findings besides comparing them with the existing results included in the literature.

Chapter 5 provides a summary of the key findings in the light of the research and puts forward some recommendations for the future studies

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Book Chapter

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Prize/Award

1. **GOLD** – Virtual Research and Innovation Exhibition, EREKA, UNIMAP February 2021. Product : BIOBiG (Biodiesel Biji Getah)
2. **BRONZE** – Karnival Inovasi UTeMEX 2019, UTeM, October 2019.
   Product : MARVEL FUEL