UNIVERSITI PUTRA MALAYSIA

SYNTHESIS AND CHARACTERIZATION OF CALCIUM-BASED CATALYSTS FOR TRANSESTERIFICATION OF JATROPHA CURCUS L. AND NANNOCHLOROPSIS OCULATA OILS TO BIODIESEL

TEO SIOW HWA

FS 2015 86

SYNTHESIS AND CHARACTERIZATION OF CALCIUM-BASED CATALYSTS FOR TRANSESTERIFICATION OF *JATROPHA CURCUS* L. AND *NANNOCHLOROPSIS OCULATA* OILS TO BIODIESEL

By

TEO SIOW HWA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2015

Special Dedicated To My Precious Parents Who Always Give Me Fabulous Love, Spectacular Care And Continued Support.

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy

SYNTHESIS AND CHARACTERIZATION OF CALCIUM-BASED CATALYSTS FOR TRANSESTERIFICATION OF *JATROPHA CURCUS* L. AND *NANNOCHLOROPSIS OCULATA* OILS TO BIODIESEL

By

TEO SIOW HWA

April 2015

Chairman: Professor Taufiq Yap Yun Hin, PhD, CChem, FRSC (UK), FASc
Faculty: Science

Catalyst plays an important role in biodiesel production. The current transesterification technology using homogeneous liquid catalysts in biodiesel production process is uneconomical, largely due to liquid catalyst is corrosive, difficult to be separated and regenerated in order to reuse. Additional, the high price of biodiesel is largely due to feedstock prices. Therefore, biodiesel price can be reduced by utilizing non-edible oil feedstock and heterogeneous solid catalysis on transesterification reaction for biodiesel production. The use of heterogeneous catalysis on the other hand, prevents the undesirable saponification, allows process simplification and offers reduction in the processing cost.

In this study, fatty acid methyl ester (FAME) was synthesized by transesterification of *Jatropha curcas* L. crude oil with methanol using calcium based heterogeneous catalysts. The initial part of this project was to synthesize the catalysts and followed by characterized the prepared catalysts *i.e.* calcium lanthanum ($CaO\text{-}La_2O_3$), calcium cerium ($CaO\text{-}CeO_2$), calcium nickel ($CaO\text{-}NiO_2$), calcium neodymium ($CaO\text{-}Nd_2O_3$) and calcium methoxide ($Ca(OCH_3)_2$). The optimization of the transesterification of *J. curcas* crude oil using different heterogeneous calcium based catalysts was evaluated. The relative order of effectiveness on transesterification was $Ca(OCH_3)_2 > CaO\text{-}CeO_2 > CaO\text{-}La_2O_3 > CaO\text{-}NiO_2 > CaO\text{-}Nd_2O_3$. The TPD results demonstrated that mixed metal oxides that prepared by co-precipitation method, showed an extremely high FAME yield (85~95%) due to the presence of stronger basic strength on the catalytic site of catalysts. Moreover, all catalysts can be regenerate and reuse. The produced FAME is met ASTM D6751 and European 14214 international biodiesel standards.

In the second part of investigation, cultivation, extraction and methanolysis of crude microalga's (*Nannochoropsis oculata*) oil were carried out. Catalytic screening was performed on $Ca(OCH_3)_2$ and mixed oxide catalysts, where $Ca(OCH_3)_2$ catalyst revealed to be the superior performance in fast conversion of microalgae derived crude oil to FAME using transesterification technique. $Ca(OCH_3)_2$ was prepared via hydrothermal route, resulted in a catalyst with surface area, total pore volume and average pore diameter of 30.5 m^2 g^{-1}, 0.21 cm^3 g^{-1} and 31.97 nm, respectively. Photoautotrophic cultivated *N. oculata*, then followed by treansesterificaition of extracted crude oil with methanol in the presence of $Ca(OCH_3)_2$ catalyst, gave a FAME yield of 95.78 %. It was observed that methanol volume and catalyst concentration were the important factors attributed to high yield of biodiesel from crude microalgae oil. The experiment results showed that catalytic transesterification technique has the potential to provide energy-efficient routes for biodiesel production form algae biomass.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SINTESIS DAN PENCIRIAN MANGKIN BERASASKAN KALSIUM UNTUK TRANSESTERIFIKASI MINYAK *JATROPHA CURCUS* L. DAN *NANNOCHLOROPSIS OCULATA* KEPADA BIODIESEL

Oleh

TEO SIOW HWA

April 2015

Pengerusi: Profesor Taufiq Yap Yun Hin, PhD, CChem, FRSC (UK), FASc
Fakulti: Sains

Mangkin memainkan peranan yang penting dalam penghasilan biodiesel. Teknologi transesterifikasi yang sedia ada dengan menggunakan mangkin cecair homogen dalam process penghasilan biodiesel adalah tidak berekonomik disebabkan oleh mangkin yang manghakis, sukar untuk dipisahkan dan diperbaharui untuk tujuan digunapakai semula. Di samping itu, biodiesel yang berharga tinggi sebahagian besarnya adalah akibat daripada harga bahan mentah yang mahal. Oleh sebab itu, harga biodiesel boleh dikurangkan dengan menggunakan bahan mentah daripada sumber minyak yang tidak boleh dimakan dan pemangkinan pepejal heterogen pada tindak balas transesterifikasi untuk penghasilan biodiesel. Sebaliknya, penggunaan pemangkinan heterogen telah mangelakkan saponifikasi yang tidak diingini, mempermudahan proses dan mengurangkan kos pemprosesan.

Dalam kajian ini, asid lemak metil ester (FAME) telah disintesis melalui transesterifikasi minyak mentah *Jatropha curcas* L. dengan metanol menggunakan mangkin heterogen berasaskan kalsium. Bahagian awal projek ini adalah untuk mensintesis mangkin dan diikuti dengan pencirian ke atas mangkin yang disediakan, iaitu kalsium lanthanum ($CaO\text{-}La_2O_3$), kalsium serium ($CaO\text{-}CeO_2$), kalsium nikel ($CaO\text{-}NiO_2$), kalsium neodimium ($CaO\text{-}Nd_2O_3$) and calcium metoksida ($Ca(OCH_3)_2$). Pengoptimuman transesterifikasi daripada minyak mentah *J. curcas* L. telah dinilaikan dengan menggunakan mangkin heterogen berasaskan kalsium yang berbeza. Susunan relatif bagi keberkesanan transesterifikasi ialah $Ca(OCH_3)_2 > CaO\text{-}CeO_2 > CaO\text{-}La_2O_3 > CaO\text{-}NiO_2 > CaO\text{-}Nd_2O_3$. Keputusan TPD menunjukkan bahawa campuran oksida logam yang disediakan dengan kaedah mendakan bersama, menghasilan FAME yang tinggi (85~95%) disebabkan oleh kehadiran akali kuat yang lebih kukuh pada tapak pemangkin. Tambahan pula, kesemua mangkin ini boleh diperbaharui dan digunapakai semula. FAME yang dihasilkan telah memenuhi piawaian biodiesel ASTM D6751 dan European 14214 diperingkat antarabangsa.

Dalam bahagian kedua penyelidikan, pengkulturan, pengekstrakan dan metanolisis minyak mentah microalga (*Nannochoropsis oculata*) telah dijalankan. Pemeriksaan ke atas mangkin telah dilakukan ke atas $Ca(OCH_3)_2$ dan mangkin-mangkin campuran oksida, dimana mangkin $Ca(OCH_3)_2$ didapati menunjukkan prestasi yang unggul dalam penukaran yang cepat minyak mentah hasilan microalga kepada FAME dengan menggunakan teknik transesterifikasi. $Ca(OCH_3)_2$ yang disediakan melalui cara sintesis hidroterma ini mempunyai luas permukaan, jumlah isipadu liang dan purata diameter liang masing-masing sebanyak 30.5 $m^2 g^{-1}$, 0.21 $cm^3 g^{-1}$ dan 31.97 nm. Pengkulturan *N. oculata* secara fotoautotrofik, kemudian diikuti oleh transesterifikasi minyak mentah dengan metanol dalam kehadiran mangkin $Ca(OCH_3)_2$, memberi hasilan FAME sebanyak 95.78%. Ini dapat diperhatikan dengan isipadu metanol dan kepekatan mangkin merupakan factor yang penting dalam penyumbangan kepada hasilan tinggi biodiesel daripada minyak mentah microalgae. Keputusan-keputusan eksperimen telah menunjukkan bahawa kaedah pemangkin transesterifikasi adalah berpotensi untuk memberi langkah yang cekap tenaga bagi penghasilan biodiesel daripada algae biomass.

ACKNOWLEDGEMENTS

First and foremost I would like to thank my supervisor, Professor Dr. Taufiq Yap Yun Hin for his infinite perseverance, enthusiasm, patient, guidance and assistance throughout my time of doctoral research. My special thanks also dedicated to co-supervisors, Professor Dr. Mohd. Zobir Hussein, Professor Dr. Azni Bin Hj Idris and Professor Dr. Lee Keat Theong.

Not to forget to convey my deepest gratitude and sincere to the staffs and technicians in the Chemistry Department, Faculty of Science for being helpful to me in the characterization works. Not to forget to officers in Electron Microscopy Unit, Institute Bioscience for their help and advice in running SEM and TEM analysis.

I am also very grateful to Dr. Aminul Islam, Dr. Wong Yee Ching, Miss Nurul Suziana Nawi @ Mohamed, Mr. Lai Fok How, Mr. Wong Hong Ren, Mr. Davin Yap Kin Yew, colleagues and friends for their help, support and discussion during my stay in the Catalysis Science and Technology Research Centre (PutraCAT), Universiti Putra Malaysia. Thank to Dr. Umer Rashid for his valuable help during the completion of my research.

Lastly, I wish to thank my beloved parents for their love, endless support and encouragement throughout my studies. I would like to say that all my academic and professional credits go to them.

Financial support from Ministry of Education (MOE) Malaysia through My PhD under Program MyBrain15 is gratefully acknowledged.

I certify that a Thesis Examination Committee has met on 30 April 2015 to conduct the final examination of Teo Siow Hwa on his thesis entitled "Synthesis and Characterization of Calcium-Based Catalysts for Transesterification of *Jatropha curcas* L. and *Nannochloropsis oculata* Oils to Biodiesel" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Gwendoline Ee Cheng Lian, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Zulkarnain Zainal, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Mansor bin Hj Ahmad @ Ayob, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Motonobu Goto, PhD
Professor
Nagoya University
Japan
(External Examiner)

_____
ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 17 June 2015

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the Doctor of Philosophy. The members of the Supervisory Committee were as follow:

Taufiq Yap Yun Hin, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Mohd. Zobir Hussein, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Azni Bin Hj Idris, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Lee Keat Teong
Professor
School of Chemical Engineering
Universiti Science Malaysia
(Member)

_____
BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision.
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to

Signature: _____	Signature: _____
Name of Chairman of Supervisory Committee: _____	Name of Member of Supervisory Committee: _____
Signature: _____	Signature: _____
Name of Member of Supervisory Committee: _____	Name of Member of Supervisory Committee: _____

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

v	Adsorbed gas quality
P	Actual gas pressure
V	Adsorbed gas quality
$MW_{fatty\ acid}$	Average molecular weight of fatty acid
$MW_{glycerol}$	Average molecular weight of glycerol
M	Average molecular weight of *J. curcas* crude oil
MW_{oil}	Average molecular weight of microalga's crude oil
MW_{water}	Average molecular weight of water
c	BET constant
R_1, R_2, R_3	Carbon chain of fatty acid
C_{IS}	Concentration of the internal standard
Cu	Copper
t	Crystallite size for (*hkl*) phase in nm
βhkl	Full width at half maximum (FWHM) at (hkl) peak in radian
A_{IS}	Internal standard peak area
T_{max}	Maxima temperature
R	Mixture of fatty acid chain
v_m	Monolayer adsorbed gas quality
k_1	Rate reaction from forward reaction
$k_{1'}$	Rate reaction from backward reaction
T	Reaction temperature
t	Reaction time
P	Reaction pressure
P/P_o	Relative pressure
$\sum A$	Total peak area of fatty acid methyl esters

S_{BET}	Total surface area
P_o	Vapour pressure
V_{IS}	Volume of the internal standard

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectroscopy
AOAC	Association of Official Analytical Chemist
ATR-FTIR	Attenuated Total Reflection-Fourier Transform Infrared
AV	Acid Value
BET	Brunauer-Emmer-Teller
BJH	Barrett–Joyner–Halenda
CFPP	Cold Filter Plugging Point
CO_2-TPD	Temperature Programmed Desorption in Carbon Dioxide
CP	Cloud Point
DG	Diglyceride
DHA	Docosahexaenoic Acid
EDX	Energy Dispersion X-ray
EN	European
EPA	Eicosapentaenoic Acid
FA	Fatty Acid
FAAE	Fatty Acid Alkyl Ester
FAEE	Fatty Acid Ethyl Ester
FAME	Fatty Acid Methyl Ester
FFA	Free Fatty Acid
FID	Flame Ionization Detector
FIP	French Institute of Petroleum
FP	Flash Point
FWHM	Full-Width at Half Maximum
GCMS	Gas Chromatography Mass Spectroscopy
HT	Hydrotalcite

ICP–AES	Inductively Coupled plasma-atomic emission spectrometric
ICDD	International Centre for Diffraction Data
IR	Infrared
JCOME	*Jatropha curcus* Oil Methyl Ester
JCPDS	Joint Committee on Powder Diffraction Standards
LED	Light Emitted Diod
MG	Monoglyceride
MPOB	Malaysian palm Oil Board
n.d.	Not dectected
n.r.	Not reported
OS	Oxidative Stability
PET	Polyethylene terephthalate
PME	Palm Oil Methyl Ester
PP	Pour Point
ppm	Parts per million
psi	Pounds per square inch
SCM	Supercritical Methanol
SD	Standard Deviation
SEM	Scanning Electron Microscopy
SFA	Saturated Fatty Acid
SME	Soybean Methyl Ester
SV	Saponification Value
SunMe	Sunflower Oil Methyl Ester
TCD	Thermal Conductivity Detector
TEM	Transmission Electron Microscopic

TG/DTA	Thermogravimetric and Differential Thermal Analysis
TG	Triglyceride
tr	Trace Amount
TW/y	Terawatt per year
USFA	Unsaturated Fatty Acid
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

CHAPTER 1

INTRODUCTION

1.1 Research Background

Petroleum has been the most main fuel needs for current vehicular fuel; the global consumption of petroleum diesel is 934 million tonnes per year (Kulkarni and Dalai, 2006). Diesel-powered vehicles represent approximately one-third of vehicles sold in Europe and United States (Jayed *et al.*, 2009). However, there has been increasing concern about energy security high oil prices caused by prospective petroleum depletion.

Instead, biofuels and biomass based energy have prospective to develop into a major contribution of energy in the next century. For instance, biomass has been recognized by worldwide to be the only sustainable source for generate liquid fuels (Klass, 1988; Huber *et al.*, 2006). Apart from that, biodiesel and bioethanol account for the major proportion of biofuels produced from crops and biomass. Approximately 90% of the biofuels which use in road vehicles is imprisoned by biodiesel and bioethanol (Juan *et al.*, 2011).

Triglycerides, which are mainly from vegetable oils and animal fats, consist of three long chain fatty acids esterifies to a glycerol structure, are highly-density energy liquid molecules with different physical and chemical properties. Transesterification reaction or also known as alcoholysis, is a main catalyzed chemical reaction for biodiesel production between triglycerides and alcohol *i.e.* methanol or ethanol to produce fatty acid methyl ester (FAME) and glycerol as a by-product (Vasudevan and Briggs, 2008) depicted in Figure 1.1.

Generally, transesterification reaction can proceed without or with the presence of catalyst. The reaction is proceeding in an extremely slow rate without any catalysts due to the two phase nature of oil and alcohol (Marchetti *et al.*, 2007). On the other hand, transesterification of triglycerides also can take place without a catalyst at high temperature (573-623 K) and high pressure (about 50 MPa) (warabi *et al.*, 2004a; Saka *et al.*, 2006). However, these intense reaction conditions are not economically. In order to solve the problems, catalysts such as homogeneous, heterogeneous or enzymatic are added to the reaction system with aim of enhance the reaction rate and increase the yield of biodiesel.

Homogeneous transesterification reaction can be either catalyzed by acidic or alkaline. Industrially, sulfuric acid, hydrochloric acid, sodium (or potassium) hydroxide or methoxide are most often used homogeneous catalysts in the conventional commercial plants producing biodiesel from vegetable oils. Homogeneous base catalysts are preferred because they much more active and less corrosive to the processing equipment than the homogeneous acid catalysts. However, the main disadvantage of homogeneous-base catalyzed reaction is that the formation of an unwanted soap by-product in the presence of water and free acid (FFA).

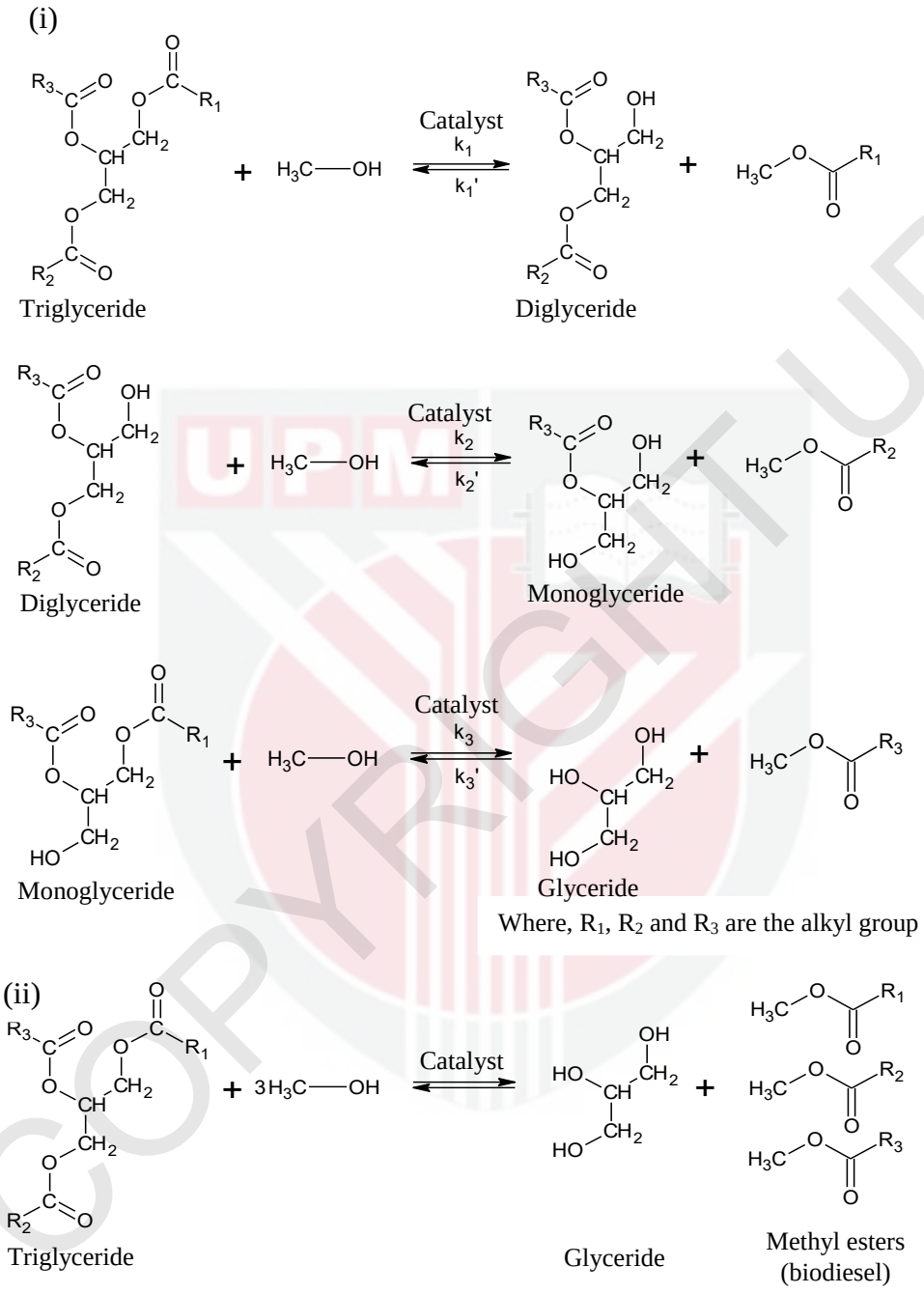

Figure 1.1 Stepwise (i) and overall transesterification (ii) reactions (Adapted from Lakhya *et al.*, 2014; Islam *et al.*, 2014)

For industry viewpoint, homogeneous catalysts are corrosive, use only once with difficulty separation process of biodiesel and catalyst, and generated a massive amount of waste water which eventually increase the overall biodiesel production cost and being not environmentally benign (Fukuda *et al.*, 2001; Van, 2005; Lam *et al.*, 2010; Shajaratun *et al.*, 2014). Next, one of the main attempts to solve drawbacks mentioned above is to replace homogeneous and enzymatic catalysts by heterogeneous catalysts towards a more sustainable industry. Developing an effective heterogeneous catalyst for biodiesel production would be beneficial, since heterogeneous catalysts offer many advantages than homogeneous catalysts in both of economic and environmental protection point of view such as (i) easy to carry and storage, (ii) simplify the separation of catalyst from product (iii) elimination of washing step (iv) long lifetimes, (v) higher efficiency and profitability of the process and (vi) lowering the production cost. Hence, using heterogeneous catalysts catalyzed biodiesel production has high potential to be eco-friendly process and promising alternative to the chemical process.

1.2 Problem Statement/ Hypothesis

Catalyst plays an important role in biodiesel production. In the chemical process industries, utilized homogeneous catalysts in biodiesel production process are ultimately wasted. In fact, alkali-catalysed transesterification reaction results in difficult to remove the liquid form catalyst from biodiesel product. Additional step is necessary to remove the alkaline catalyst that markup the biodiesel cost production. Moreover, waste is also associated with the use of acids to neutralize the reaction after product formation, and wastewater generated from 'washing' the biodiesel product result in loss of homogeneous catalyst.

Sustainable biodiesel production has now focused on production efficiency with minimal waste generation to enhance resource productivity. The need to minimize materials and energy consumption by development of a suitable heterogeneous catalyst and discovery other potential biodiesel feedstocks will be the major crucial in making biodiesel. Nevertheless, a stable catalyst that can be recycled and reused to simplify the product separation and purification steps remains inadequately addressed. Therefore, it is compulsory to discover a suitable and flexible catalyst for transesterification of plant derived oil *Jatropha curcas* (*J. curcas*) and *Nannochloropsis oculata* (*N. oculata*)).

The first approach on catalyst development is to prepare the calcium-based mixed oxides ($CaO\text{-}La_2O_3$, $CaO\text{-}CeO_2$, CaO-NiO and $CaO\text{-}Nd_2O_3$) via co-precipitation process using highly basic precipitate. Overall, this process had been optimized by varies the synthesis parameter such as molar ratio of metal compositions and pH value of precipitation. The second approach of calcium-based catalyst focused on bulk type whereby the structure and morphology of $Ca(OCH_3)_2$ catalyst were determined in order to optimize the synthesis parameter prior to the production of nano-architectures $Ca(OCH_3)_2$ catalyst.

For comparison of catalytic activity on biodiesel production, *J. curcas* crude oil and extracted *N. oculata* crude oil were used as potential triglycerides source in transesterification reaction. Physico-chemical properties mixed metal oxide catalysts were characterized and also applied for transesterification *J. curcas* crude oil with methanol. Whereas, nano particle $Ca(OCH_3)_2$ catalyst was tested for transesterification reaction and its performance in biodiesel production from two different feedstocks: the

J. curcas and the *N. oculata* microalgae crude oils were evaluated in term of FAME yield and catalyst reusability. The overall process flow of research is shown in Figure 1.2.

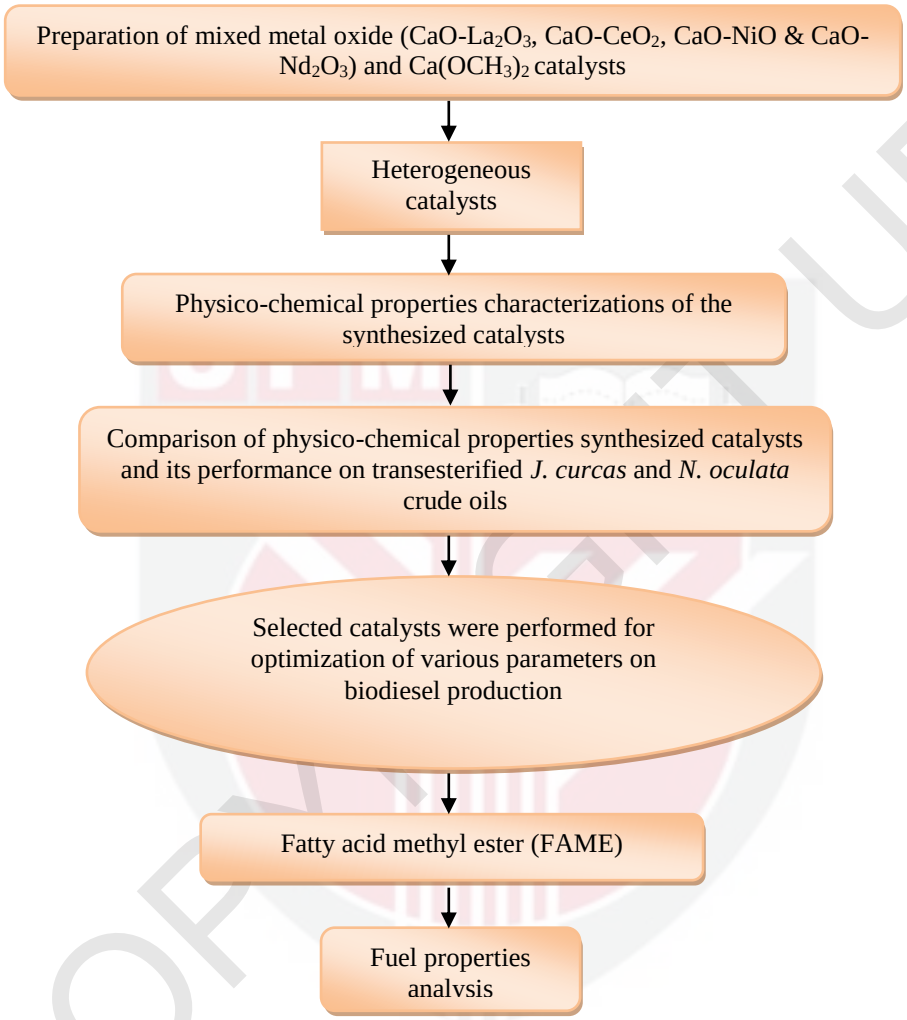

Figure 1.2 Overall diagram of research activities

1.3 Scope of Research

This studies involved synthesis of mixed metal oxide and $Ca(OCH_3)_2$ heterogeneous catalysts for biodiesel production from vegetable (*J. curcas*) and microalgae (*N. oculata*) crude oils with methanol.The effect of catalyst preparation condition *i.e.* molar ratio of metal oxide and pH value to synthesis in catalyst performance was investigated. The physic-chemicals characteristics of catalysts were carried out by using several methods (TGA, XRD, BET, FTIR, XRF, TPD, SEM and TEM). The surface properties of the supported catalysts were analyzed using N_2 adsorption/desorption isotherms and the basicity properties, evaluated in terms of

number and strength of basic sites, were analyzed using CO_2-temperature-programmed reduction (CO_2-TPD) techniques. In addition, the structural characteristic of the synthesized catalysts was carried out using XRD. The condition of the transesterification reactions of *J. curcas* crude oil was also studied by investigating the effect of variable transesterification parameters on biodiesel production such as catalyst concentration, methanol/ oil molar ratio, reaction temperature and time. The reusability of the catalyst was determined and the leachate of catalyst into the reaction product was verified by inductively coupled plasma-atomic emission spectrometric (ICP–AES) and absorption spectroscopy (AAS) elemental analysis. The relationship between the basicity of the catalyst and their catalytic activity in the transesterification of *J. curcas* crude oil is also discussed. Next, the selected $Ca(OCH_3)_2$ was use as catalyst and evaluated its performance in transesterification reaction of *N. oculata* crude oil with methanol at 60 ^oC in batch process in terms of biodiesel yield and catalyst reusability. The composition of biodiesel was evaluated by the gas chromatography method. In addition, the fuel properties characterization of biodiesel produced from transesterification of *J. curcas* crude oil with methanol was performed according to the ASTM D6751 and European 14214 standard specifications.

1.4 Objectives

This dissertation is aimed to develop calcium-based mixed oxide and calcium methoxide ($Ca(OCH_3)_2$) catalysts. This study also concerned with the physical and chemical properties of synthesized catalysts and the feasibility of biodiesel production from *J. curcas* and *N. oculata* through transesterification reaction with methanol. Various characterization techniques have been carried out. In order to achieve the main aim, a total of six research objectives have been addressed as follow:

1. To synthesize binary oxide calcium-based heterogeneous catalysts by co-precipitation method.
2. To prepare $Ca(OCH_3)_2$ heterogeneous catalyst using hydrothermal route.
3. To investigate the physico-chemical characteristics of catalysts.
4. To optimize the condition of the transesterification reactions of jatropha and microalgae oils by investigate the transesterification variables.
5. To chacterize the jatropha and FAME product of its quality as diesel substitute.
6. To determine the reusability of the catalysts.

BIBLIOGRAPHY

Aarthy, M., Saravanan, P., Gowthaman, M.K., Rose, C. and Kamini, N.R. (2014). Enzymatic transesterification for production of biodiesel using yeast lipases: An overview. *Chemical Engineering Reseach and Design.* **92**: 1591-1601.

Abdelmalik, A.A., Abbott, A.P., Fothergill, J.C., Dodd, S. and Harris, R.C. (2011). Synthesis of a basestock for electrical insulating fluid based on palm kernel oil. *Industrial Crops and Products.* **33**: 532-536.

Abdullah, G.A.S., Ayed S.A.S., Abul, K., Du, G.H. and Tokeer, A. (2014). Microwave synthesis, optical properties and surface area studies of NiO nanoparticles. *Journal of Molecular Structure.* **1058**: 56-61.

Achten, W.M.J., Verchot, L., Franken Y.J., Marthijs, E., Singh, V.P., Aerts, R. and Muys, B. (2008). Jatropha biodiesel production and use. *Biomass and Bioenergy.* **32**: 1063-1084.

Agarwal, A.K. (2007). Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Progress in Energy and Combustion Science.* **33(3)**: 233-271.

Agarwal, D. and Agarwal, A.K., (2007). Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. *Applied Thermal Engineering.* **27**: 2314-2323.

Ahmad, G. and Oki M. (2014). Biodiesel production from algae by using heterogeneous catalysts: A critical review. *Energy.* **78**: 72-83.

Aksoy, H.A., Becerik, I., Karaosmanoglu, F., Yamaz, H.C. and Civelekoglu, H, (1990). Utilization prospects of Turkish raisin seed oil as an alternative engine fuel. *Fuel.* **69**: 600-603.

Amigun, B., Sigamoney, R. and Blottnitz, H.V. (2008). Commercialisation of biofuel industry in Africa: a review. *Renewable Sustainable Energy Reviews.* **12**: 690-711.

Amish, P. V., Jaswant, L. and Subrahmanyam, N. (2010). A review o FAME production process. *Fuel.* **89(1)**: 1-9.

Amjad, A. and Navjot, K. (2014). Kinetic and reusability of Zr/CaO as heterogeneous catalyst for ethanolysis and methanolysis of *Jatropha curcas* oil. *Fuel Processing Technology.* **119**: 173-184.

Ana P.A, Bruno F., Antonio A.V, Jose T. and Giuliano D. (2012). Mixotrophic cultivation of *Chlorella vulgaris* using industrial dairy waste as organic carbon source. *Bioresources Technology.* **118**: 61-66.

Antunes, W.M., Veloso, C.O. and Henriques, C.A. (2008). Transesterification of soybean oil with methanol catalyzed by basic solids. *Catalysis Today.* **133-135**: 548-554.

Arifin, A.A., Bakar, J., Tan, C.P., Rahman, R.A., Krim, R. and Loi, C.C. (2009). Essential fatty acids of Pitaya (Dragon fruit) seed oil. *Food Chemistry.* **114**: 561-564.

Arzamendi, G., Campo, I., Arguinarona, E., Sanchez, and Gandia, L.M. (2008). Alkaline and alkaline-earth metals compounds as catalysts for the methanolysis of sunflower oil. *Catalysis Today.* **133-135**: 305-313.

Babu, N.S., Rekha, S., Prasad, P.S.S. and Lingaiah, N. (2008). Room temperature transesterification of edible and nonedible oils using a heterogeneous strong basic Mg/La catalyst. *Energy & Fuels.* **22(3)**: 1965-1971.

Bahadar, A. and Khan, M.B. (2013). Progress in energy from microalgae: A review. *Renewable Sustainable Energy Reviews.* **27**: 128-148.

Bai, H.X., Shen, X.Z., Liu, X.H. and Liu, S.Y. (2009). Synthesis of porous CaO microsphere and its application in catalyzing transesterification reaction for biodiesel. *Transactions of Nonferrous Metals Society of China*. **19**: 674-677.

Balat, M. and Balat, H. (2008). A critical review of bio-diesel as a vehicular fuel. *Energy Conversion and Management.* **49**: 2727-2741.

Barkley, W.R., Lewin, R.A. and Cheng, L. (1988). In: Sadler T, editor. Development of microalgal systems for the production of liquid fuels. Villeneuve d'Ascq, France, 55-65. London, New York, USA. Elsevier Applied Science.

Barnwal, B.K. and Sharma, M.P. (2005). Prospects of biodiesel production from vegetable oils in India. *Renewable Sustainable Energy Reviews.* **9(4)**: 363-378.

Becker, E.W. (1994). Microalgae: biotechnology and microbiology. Cambridge: Cambridge University Press.

Belarbi, E.H., Molina, G.E. and Chisti, Y. (2000). A process for high yield and scaleable recovery of high purity eicosapentaenoic acid esters from microalgae and fish oil. *Enzyme and Microbial Technology.* **26**: 516-529.

Benemann, J.R. (2008). Opportunities and challenges in algae biofuels production. Position paper, Algae World 2008, Singapore.

Berchmans, H.J., Morishita, K. and Takarada, T. (2013). Kinetic study of hydroxide catalyzed methanolysis of *Jatropha curcas*-waste food oil mixture for biodiesel production. *Fuel.* **104**: 46-52.

Bhaskar, S., Abhishek, G., Ismail, R. and Faizal, B. (2014). Towards a sustainable approach for development of biodiesel from plant and microalgae. *Renewable and Sustainable Energy Reviews.* **29**: 216-245.

Biernat, K., Malinowski, A. and Gnat, M. (2012). The possibility of future biofuels production using waste carbon dioxide and solar energy. Biofuels - economy, environment and sustainability. *Intech.* 123-172.

Bologinini, M., Cavani, F., Scagliarini, D., Flego, C., Perego, C. and Saba, M. (2003). Mg/Al mixed oxides prepared by coprecipitation and sol-gel routes: a comparison of their physic-chemical features and performances in m-cresol methylation. *Microporous and Mesoporous Materials.* **66**: 77-89.

Borges, M.E. and Díaz, L. (2012). Recent developments on heterogeneous catalysts for biodiesel production by oil esterification and transesterification reactions: A review *Renewable Sustanable Energy Reviews.* **16**: 2839-2849.

Boris, W. and Brian, H.H. (2010). Rapid, colorimetric quantification of lipid from algal cultures. *Journal of Microbioligical Methods.* **80**: 262-266.

Borowitzka, M.A. and Borowitzka, L.J. (1988). Microalgal biotechnology. Cambridge: Cambridge University Press.

Bournay, L., Casanave, D., Delfort, B., Hillion, G. and Chodorge, J.A. (2005a). New heterogeneous process for biodiesel production: A way to improve the quality and the value of the crude glycerin produced by biodiesel plants. *Catalysis Today.* **106(1-4)**: 190-192.

Bournay, L., Hillion, G., Boucot, P., Chodorge, J.A., Bronner, C. and Forestiere, A. (2005b). Process of Producing Alkyl Esters from Vegetable or Animal Oil and Aliphatic Monoalcohol. U.S. Patent 6878837.

Canakci, M. and Van Gerpen, J. (2004). A polot plant to produce biodiesel from high free fatty acid feedstocks. *Transactions of the American Society of Agricultural Engineers.* **46**: 945-955.

Cao, P., Dube, M.A. and Tremblay, A.Y. (2009). High-purity fatty acid methyl ester production from canola, soybean, palm, and yellow grease lipids by means of amembrane reactor. *Biomass and Bioenergy.* **32**: 1028-1036.

Carrero, A., Vicente, G., Rodrı′guez, R., Linares, M. and del Peso, G.L. (2011). Hierarchical zeolites as catalysts for biodiesel production from *Nannochloropsis* microalga oil. *Catalysis Today.* **167**: 148-153.

Chen, G.Q., Jiang, Y. and Chen, F. (2008). Variation of lipid class composition in *Nitzschia laevis* as a response to growth temperature change. *Food Chemistry.* **109(1)**: 88-94.

Chen, L., Liu, T.Z., Zhang, W., Chen, X.L. and Wang, J.F. (2012). Biodiesel production from algae oil high in free fatty acids by two-step catalytic conversion. *Bioresources Technology.* **111**: 208-214.

Chi, Z.Y., Hu, B., Liu, Y., Frear, C., Wen, Z. Y. and Chen, S. L. (2007). Production of omega-3 polyunsaturated fatty acids from cull potato using an algae culture process. *Applied Biochemistry and Biotechnology.* **137**: 805-815.

Chisti, Y. (2007). Biodiesel from microalgae. *Biotechnology Advances.* **25**: 294-306.

Chitra, P., Venkatachalam, P. and Sampathrajan, A. (2005). Optimisation of experimental procedure for biodiesel production from alkaline-catalysed transesterification of *Jatropha curcas* oil. *Energy for Sustainable Development.* **9**: 13-18.

Chopade, G., Kulkarni, K.S., Kulkarni, A.D. and Topare, S. (2012). Solid heterogeneous catalysts for production of biodiesel from trans-esterification of triglycerides with methanol: a review. *Acta Chimica and Pharmaceutica Indica.* **2(1)**: 8-14.

Choudary, A., Kantam, M., Reddy, C., Rao, K. and Fiqueras, F. (1999). The first example of Micheal Addition catalysed by modified Mg-Al hydrotalcite. *Journal of Molecular Catalysis A: Chemical.* **146**: 279-284.

Christie, W.W., (1989). Gas chromatography and lipids : a practical guide. Oily Press, Ayr, Scotland.

Costa, J.F., Almeida, M.F., Alvim-Ferraz, M.C.M. and Dias, J.M. (2013). Biodiesel production using oil from fish canning industry wastes. *Energy Conversion and Management.* **74**: 17-23.

Cruz, A.D., Kulkarni, M.G. Meher, L.C. and Dalai, A.K. (2007). Synthesis of biodiesel from canola oil using heterogeneous base catalyst. *Journal of the American Chemical Society*, **84**: 937-943.

Cullity, B.D. (1978). Elements of X-ray diffaction. London: Addison-Wesley.

Cynthia, A.P. (2008). Jatropha: the next big thing in biofuel? Malaysian Business. Available from find articles.com. (accessed May 2014).

Da Silva R.B., Neto, A.F.L., dos Santos, L.S.S., Chaves, M.H. et al. (2008). Catalyst of Cu(II) and Co(II) ions adsorbed in chitosan used in transesterification of soy bean and babassu oils: a new route for biodiesel synthesis. *Bioresources Technology.* **99**: 6793-6798.

Dai, Y.M., Chen, K.T. and Chen, C.C. (2014). Study of the microwave lipid extraction from microalgae for biodiesel production. *Chemical Engineering Journal.* **250**: 267-273.

De Ia Noue, J. and De Pauw, N. (1988). The potential of microalgal biotechnology: a review of production and uses of microalgae. *Biotechnology Advanced.* **6**:725-770.

Dehkordi, A.M. and Ghasemi, M. (2012). Transesterification of waste cooking oil to biodiesel using Ca and Zr mixed oxides as heterogeneous catalysts. *Fuel Processing Technology*. **97**: 45-51.

Demirbas, A. (2003). Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterification and other methods: a survey. *Energy Conversion and Management.* **44(13)**: 2093-2109.

Demirbas, A. (2007a). Biodiesel: A Realistic Fuel Aleternative for Diesel Engines. Springer, London.

Demirbas, A. (2007b). Biodiesel from sunflower oil in supercritical methanol with calcium oxide. *Energy Conversion and Management.* **48(3)**: 937-941.

Demirbas, A. (2009). Biomass resource facilities and biomass conversion processing for fuels *and chemicals. Energy Conversion and Management.* **44(13)**: 2093-2109.

Demirbas, A. and Kara, H. (2006). New options for conversion of vegetable oils to alternative fuels. *Energy Source Part A: Recovery Utilization and Environment Effects.* **28**: 619-626.

Deng, L., Xu, X.B., Tan, T.W. and Wang, F. (2005). A review of the current state of biodiesel production using enzymatic transesterification. *Journal of the American Oil Chemist's Society.* **82(5)**: 341-347.

Deng, X., Fang, Z., Liu, Y.H. and Yu, C.L. (2001). Production of biodiesel from Jatropha oil catalyzed by nanosized solid basic catalyst. *Energy.* **36**: 777-784.

Di Serio, M., Ledda, M., Cozzolino, M., Minutillo, G., Tesser, R. and Santacesaria, E. (2006). Transesterification of soybean oil to biodiesel by using heterogeneous basic catalysts. *Industrial & Engineering Chemistry Research*. **45(9)**: 3009-3014.

Eckey, E.W. (1956). Esterification and interesterification. *Journal of the American Oil Chemist's Society.* **33**: 575-579.

Ejikeme, P.M, Anyaogus, I.D., Ejikeke, C.L. and Engbuonu, C.A.C (2010). Catalyst in biodiesel production by transesterification processes-an inslight. *E-Journal of Chemistry.* **7(4)**: 1120-1132.

Emil, A., Zahira Y., Siti, K.K., Manal, I. and Jumat, S. (2009). Chatacteristic and composition of Jatropha curcas and its pontential as biodiesel feedstock. *European Journal of Scientific Research.* **29(3)**: 396-403.

FAO (2012). Food and Agriculture Organization. Oil seeds market summary, Trade and Markets Division, Food outlook 2012 (online). http://www.fao.org/fileadmin/templates/est/COMM_M (Accessed March 2014).

Felizardo P., Neiva Correia M.J., Raposo I., Mendes J.F., Berkemeier R. and Bordado J.M. (2006). Production of biodiesel from waste frying oils. *Waste Management.* **26**: 487-494.

Freedman, B., Butterfield, R.O. and Pryde, E.H. (1986). Transesterification kinetic of soybean oil. *Journal of the American Oil Chemist's Society.* **63**: 1375-1380.

Fuentes-Grünewald, C., Garcés, E., Rossi, S. and Camp, J. (2009). Use of the dinoflagellate Karlodinium veneficum as a sustainable source of biodiesel production. *Journal of Industrial Microbiology and Biotechnology*. **36**: 1215-1224.

Fukuda, H., Konda, A. and Noda, N. (2001). Biodiesel fuel production by transesterification of oils. *Journal of Bioscience and Bioengineering.* **92(5)**: 405-416.

Gabriel, P., Holbrook, Z., Davidson, R.A.T., Norbert L.Z.K.A. and Rosentrater, W.S.G. (2014*).* Use of the microalga *Monoraphidium* sp. grown in wastewater as a feedstock for biodiesel: cultivation and fuel characteristics. *Applied Energy.* **131**: 386-393.

Goff, M.J., Bauer, N.S., Lopes, S., Sutterlin, W.R. and Suppes, G.J., (2004). Acid-catalyzed alcoholysis of soybean *oil. Journal of the American Oil Chemist's Society*.**81**: 415-420.

Granados, M.L., Alonso, D.M., Sádaba, I., Mariscal, R., Ocón, P. (2009). Leaching and homogeneous contribution in liquid phase reaction catalysed by solids: The case of triglycerides methanolysis using CaO. *Applied Catalysis B: Environmental*. **89(1-2)**: 265-272.

Granados, M.L., Poves, M.D.Z., Alonso, D.M., Mariscal, R., Galisteo, F.C., Moreno-Tost, R., et al. (2007). Biodiesel from sunflower oil by using activated calcium oxide. *Applied Catalysis B: Environment.* **73(3-4)**: 317-326.

Grobbelaar, J.U. (2004). Algal nutrition. Handbook of microalgal culture: biotechnology and applied phycology. *Blackwell.* 97-115.

Gryglewicz, S. (1999). Rapeseed oil methyl esters preparation using heterogeneous catalysts. *Bioresources Technology.* **70**: 249-253.

Guan, G., Sakurai, N. and Kusakabe, K. (2009). Synthesis of biodiesel from sunflower oil at room temperature in the presence of various cosolvents. *Chemical Engineering Journal.* **146**: 302-306.

Gui, M.M., Lee, K.T. and Bhatia, S. (2008). Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. *Energy.* **33**: 1646-1653.

Gui, M.M., Lee, K.T. and Bhatia, S. (2009). Supercritical ethanol technology for the production of biodiesel: process optimization studies. *The Journal of Supercritical Fluids.* **49(2)**: 286-292.

Hanifa, T., Sulaiman, A., Ali H.A., Yousef, H. and Mohammed, F. (2014). Effective extraction of microalgae lipids from wet biomass for biodiesel production. *Biomass and Bioenergy.* **66**: 159-167.

Hassan, M., Robiah, Y., Thomas, S.Y.C., Rashid, U. and Taufiq-Yap, Y.H. (2012). Synthesis and characterization of calcium methoxide as heterogeneous catalyst for trimethylolpropane esters conversion reaction. *Applied Catalysis A: General.* **425-426**: 184-190.

Hattori, H. (2001). Solid base catalysts: generation of basic sites and application to organic synthesis. *Applied Catalysis A: General.* **222**: 247-259.

Heller, J. (1996). Physic Nut. *Jatropha curcas* L. promising the conservation and use of underutilized and neglected crops. International Plant Genetic Resources Institute. Rome.

Helwani, Z., Othman, M.R., Aziz, N., Kim, J. and Fernando, W.J.N. (2009). Solid heterogeneous catalysts for trans-esterification of triglycerides with methanol. *Applied Catalysis A: General.* **363**: 1-10.

Hossain, A.B.M.S., Salleh, A., Boyce, A.N., Chowdhury, P. and Naqiuddin, M. (2008). Biodiesel fuel production from algae as renewable energy. *American Journal of Biochemistry and Biotechnology.* **4**: 250-254

Hoydonckx, H.E., De Vos, D.E., Chavan, S.A., Jacobs, P.A. (2004). Esterification and transesterification of renewable chemicals. *Topics in Catalysis.* **27(1-4)**: 83-96.

Hu, S.Y., Guan, Y.P., Wang, Y. and Han, H.Y. (2011). Nano-magnetic catalyst KF/CaO–Fe_3O_4 for biodiesel production. *Applied Energy.* **88**: 2685-2690.

Huang, G.H., Chen, F., Wei, D., Zhang, X.W. and Chen, G. (2010). Biodiesel production by microalgal biotechnology. *Applied Energy.* **87**: 38-46.

Huber, G.W., Iborra, S., and Corma, A. (2006). Synthesis of transportation fuels from biomass: Chemistry, catalysts, and engineering. *Chemical Reviews.* **106(9)**: 4044-4098.

Illman, A.M., Scragg, A.H. and Shales S.W. (2000). Increase in *Chlorella* strains calorific values when grown in low nitrogen medium. *Enzyme and Microbial Technology.* **27(8)**: 631-635.

Islam, A., Chan, E.S., Taufiq-Yap, Y.H., Md. Alam, H.M. and Moniruzzaman, M., Mridha, M. (2014a). Energy security in Blangladesh perspective-Assessment and Implication. *Renewable and Sustainable Energy Reviews.* **32**: 154-171.

Islam, A., Taufiq-Yap, Y.H., Chan, E.S., Moniruzzaman, M., Islam, S. and Nabi, M.N. (2014b). Advances in solid-catalytic and non-catalytic technologies for biodiesel production. *Energy Conversion and Management.* **88**: 1200-1218.

Islam, A., Taufiq-Yap, Y.H., Chu, C.M., Chan, .ES. and Ravindra, P. (2013a). Studied on design of heterogeneous catalysts for biodiesel production. *Process Safety and Environmental. Protection.* **91**: 131-144.

Islam, A., Taufiq-Yap, Y.H., Chu, C.M., Ravindra, P. and Chan, E.S. (2013b). Transesterification of palm oil using KF and $NaNO_3$ catalysts supported on spherical millimetric γ- Al_2O_3. *Renewable Energy*. **59**: 23-29.

Jain, S. and Sharma, M.P., (2010). Prospects of biodiesel from Jatropha in India: a review. *Renewable Sustainable Energy Reviews.* **14**: 763-771.

Jang, J.M., Kim, C.R., Ryu, H., Razeghi, M. and Jung, W.G. (2008). ZnO 3D flower-like nanostructures synthesized on GaN epitaxial layer by simple route hydrothermal process. *Journal of Alloys and Compounds.* **463**: 503-510.

Jasmine, J.K. and Samson, A.N. (2011). Synthesis of CeO_2 nanoparticles by chemical precipitation and effect of a surfactant on the distribution of particle sizes. *Journal of Ceramic Processing Research.* **12(1)**: 74-79.

Jayed, M.H., Masjuki, H.H., Saidur, R., Kalam, M.A., Jahirul, M.I., (2009). Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. *Renewable and Sustainable Energy Reviews.* **13**: 2452-2462.

Jiang, L.L., Luo, S.J., Fan, X.L. Yang, Z.M. and Guo, R.B. (2011). Biomass and lipid production of marine microalgae using municipal wastewater and high concentration of CO_2. *Applied Energy.* **88**: 3336-3341.

Jin, B., Duan, P., Xu, Y., Wang, B., Wang, F. and Zhang, L. (2014). Lewis acid-catalyzed in situ transesterification/ esterification of microalgae in supercritical ethanol. *Bioresources Technology.* **162**: 341-349.

Jitputti, J., Kitiyanan, B., Balasoiu, M., Ivanov, A. and Jitianu, A. (2006a). Comparative study of sol-gel and coprecipitated Ni-Al hydrotalcites. *Journal of Sol-gel Science and Technology.* **19**: 453-457.

Jitputti, J., Kitiyanan, B., Rangsunvigit, P., Bunyakiat, K., Attanatho, L. and Jenvanitpanjakul, P. (2006b). Transesterification of crude palm kernel oil and crude coconut oil by different solid catalysts. *Chemical Engineering Journal.* **116**: 61-66.

Juan, J.C., Kartika, D.A., Wu, T.Y. and Taufiq-Yap, Y.H. (2011). Biodiesel production from jatropha oil by catalytic and non-catalytic approaches: An overview. *Bioresources Technology.* **102**: 452-460.

Kansedo, J., Lee, K.T. and Bathia, S. (2009). Biodiesel production from palm oil via heterogeneous transesterification. *Biomass and Bioenergy*. **33**: 271-276.

Kawashima, A., Matsubara, K. and Honda, K. (2009). Acceleration of catalytic activity of calcium oxide for biodiesel production. *Bioresources Technology.* **100**: 696-700.

Kesic, Z., Lukic, I., Brkic, D., Rogan, J., Zdujic, M. and Liu, H. (2012). Mechanochemical preparation and characterization of CaO·ZnO used as catalyst for biodiesel synthesis. *Applied Catalysis A: General*. **427-8**, 58-65.

Khan, A.K. (2001). Research into biodiesel kinetics and catalysis development, in Department of Chemical Engineering. University of Queensland: Queensland.

Khang, D.S., Razon, L.F. Madrazo, C.F. and Tan, R.R. (2014). In situ transesterification of coconut oil using mixtures of methanol and tetrahydrofuran. *Chemical Engineering Research and Design.* **92**: 1512-1218.

Khozin-Goldberg, I. and Cohen, Z. (2006). The effect of phosphate starvation on the lipid and fatty acid composition of the fresh water eustigmatophyte *Monodus subterraneus*. *Phytochemistry.* **67**: 696-701.

Kim, H., Kang, B., Kim, M. Park, Y., Kim, D., Lee, D. and Lee K. (2004). Transesterification of vegetable oil to biodiesel using heterogeneous base catalyst. *Catalysis Today.* **93**: 315-320.

Kim, M., DiMaggio, C., Yan, S., Salley, S.O. and Ng, K.Y.S. (2010). The synergistic effect of alcohol mitures on transesterification of soybean oil using homogeneous and heterogeneous catalysts. *Applied Catalysis A: General.* **378(2)**: 134-143.

Kim, M.H., Craig, D.M., Yan, S.L., Steven Salley, O. and Simon Ng, K.Y. (2011). The effect of support material in the transesterification activity of $CaO\text{-}La_2O_3$ and $CaO\text{-}CeO_2$ supported catalyst. *Green Chemistry.* **13**: 334-339.

Kitada, K., Machmudah, S., Sasaki, M., Goto, M., Nakashima, Y., Kumamoto, S., Hasegawa, T. (2009). Antioxidant and antibacterial activity of nutraceutical compounds from *Chlorella vulgaris* extracted in hydrothermal condition. *Separation Science and Technology.* **44(5)**: 1228-1239.

Klass, D.L. (1998). Biomass for renewable energy, fuels, and chemicals. SanDiego: Academic Press.

Knothe, G. (2002). Current perspectives on biodiesel. Information. **13(12):** 900-903.

Knothe, G. (2005). The history of vegetable oil-based diesel fuels. In: Knothe G, Gerpen JV, Krahl J, editors. The biodiesel handbook. Champaign, Illinois: AOCS Press.

Knothe, G.J.V.G. and Krahl J. (2004). The biodiesel handbook. AOCS Press.

Koberg, M., Cohen, M., Amotz, A.B. and Gedanken, A. (2001). Biodiesel production directly from the microalgae biomass of *Nannochlopsis* by microwave and ultrasound radiation. *Bioresources Technology.* **102**: 4265-4269.

Kondamudi, N., Mohapatra, S.K. and Misra, M. (2008). Spent coffee grounds as a versatile source of green energy. *Journal of Agricultural and Food Chemistry*. **56**: 11757-11760.

Kouzu, M. and Hidaka, J.S. (2011). Transesterification of vegetable oil into biodiesel catalyzed by CaO: a review. *Fuel.* **93**: 1-12.

Kouzu, M., Hidaka, J.S., Wakabayashi, K. and Tsunomori, M. (2010). Solid base catalysis of calcium glyceroxide for a reaction to convert vegetable oil into its methyl esters. *Applied Catalysis A: General.* **390**: 11-18.

Kouzu, M., Kasuno, T., Tajika, M., Yamanaka, S. and Hidaki, J. (2008). Active phase of calcium oxide used as solid base catalyst for transesterification of soybean oil with refluxing methanol. *Applied Catalysis A: General.* **334(1-2)**: 357-365.

Kozlowski, J.T., Aronson, M.T. and Davis, R.J. (2010). Transesterification of tributyrin with methanol over basic Mg:Zr mixed oxide catalysts. *Applied Catalysis B: Environmental* **96**: 508-515.

Krohn, B.J., McNeff, C.V., Yan, B. and Nowlan, D. (2011). Production of algae-based biodiesel using the continuous catalytic Mcgyan® process. *Bioresources Technology.* **102**: 94-100.

Kulkarni, M.G. and Dalai, A.K. (2006). Waste cooking oil - an economical source for biodiesel: a review. *Industrial & Engineering Chemistry Research.* **45**: 2901-2913.

Kumar, A. and Sharma, S., 2008. An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): a review. *Industrial Crops and Products.* **28**: 1-10.

Kumar, D. and Ali, A. (2010). Nanocrystalline lithium ion impregnated calcium oxide as heterogeneous catalyst for transesterification of high moisture containing cotton seed oil. *Energy and Fuels*. **24**: 2091-2097.

Kusdiana, D. and Saka, S. (2001). Kinetics of transesterification in rapeseed oil to biodiesel fuel as treated in supercritical methanol. Fuel. **80(5)**: 693-698.

Kusdiana, D. and Saka, S. (2004). Effects of water on biodiesel fuel production by supercritical methanol treatment. *Bioresources Technology.* **91**: 289-295.

Lai, C.C., Zullaikah, S., Vali, S.R. and Ju, Y. (2005). Lipase-catalyzed production of biodiesel from rice bran oil. *Journal of chemical Technology and Biotechnology*. **80(3)**: 331-337.

Lakhya J.K., Jutika, B. and Dhanapati, D. (2014). Review on latest developments in biodiesel production using carbon-based catalysts. *Renewable Sustainable Energy Reviews.* **29**: 546-564.

Lam, M.K., Lee, K.T. and Mohamed, A.R. (2009). Sulfated tin oxide as solid superacid catalyst for transesterification of waste cooking oil: an optimization study. *Applied Catalysis B: Envinronmental.* **93**:134-139.

Lam, M. K. and Lee, K.T. (2011). Renewable and sustainable bioenergies production from palm oil mill effluent (POME): win–win strategies toward better environmental protection *Biotechnology Advances.* **29(1)**: 124-141.

Lam, M.K. and Lee, K.T. (2013). Catalytic transesterification of high viscosity crude microalgae lipid to biodiesel: Effect of co-solvent. *Fuel Processing Technology.* **110**: 242-248.

Lam, M.K., Lee, K.L. and Mohamed, A.R. (2010). Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: A review. *Biotechnology Advances.* **28(4)**: 500-518.

Laurianne, T., Ta, M.T., Thierry, D., Konstantin, K., Valérie, H., Cyriaque, S., Caroline, A., Ivan, P.N., Alain, P., Olivier, V. and Blondea,u J.P. (2010). Application of nanostructured Ca doped CeO_2 for ultraviolet filtration. *Material Research Bulletine.* **45**: 527-535.

Lee, D.W., Park, Y.M. and Lee, K.Y. (2009). Heterogeneous base catalysts for transesterification in biodiesel synthesis. *Catalysis Survey From Asia*. **13**: 63-77.

Lee, H.V., Taufiq-Yap, Y.H., Hussein, M.Z. and Yunus, R. (2013). Transesterification of jatropha oil with methanol over Mg-Zn mixed metal oxide catalysts. *Energy.* **49**: 12-18.

Lee, H.V., Yunus, R., Juan, J.C. and Taufiq-Yap, Y.H. (2011). Process optimization design for jatropha-based production using response surface methodology. *Fuel Processing Technology*. **92**: 2420-2428.

Lee, I., Johnson, L.A. and Hammond, E.G., (1995). Use of branched-chain esters to reduce the crystallization temperature of biodiesel. *Journal of the American Oil Chemists' Society.* **72**: 1155-1160.

Leung, D.Y.C. and Guo, Y. (2006). Transesterification of neat and used frying oil: optimization for biodiesel production. *Fuel Processing Technology*. **87**: 883-890.

Leung, D.Y.C., Wu, X. and Leung, M.K.H., (2010). A review on biodiesel production using catalyzed transesterification. *Applied Energy*. **87**: 1083-1095.

Levine, R.B., Pinnarat, T. and Savage, P.E. (2010). Biodiesel production from wet algal biomass through in situ lipid hydrolysis and supercritical transesterification. *Energy and Fuels.* **24**: 5235-5243.

Li Q., Du, W. and Liu, D.H. (2008a). Perspectives of microbial oils for biodiesel production. *Applied Biochemistry and Biotechnology*. **80**: 749-756.

Li, E., Xu Z.P. and Rudolph, V. (2009). MgCoAl-LDH derived heterogeneous catalysts for the ethanol transesterification of canola oil to biodiesel. *Applied Catalysis B: Environmental*. **88**: 42-49.

Li, H.T. and Xie, W.L. (2006). Transesterification of soybean oil to biodiesel with Zn/I-2 catalyst. *Catalysis Letter*. **107**: 25-30.

Li, Y., Horsman, M., Wu, N., Lan, C.Q. and Dubois-Calero, N. (2008b). Biofuels from microalgae. *Biotechnology progress.* **24(4)**: 815-820.

Li, Y.H., Qiu, F.X., Yang, D.Y., Li, X.H. and Sun, P. (2011a). Preparation, characterization and application of heterogeneous solid base catalyst for biodiesel production from soybean oil. Biomass & Bioenergy **35**: 2787-2795.

Li, Y.S., Lian, S., Tong, D., Song, R.L., Yang, W.Y., Fan, Y., et al. (2011b). One-step production of biodiesel from *Nannochloropsis* sp. on solid base Mg-Zr catalyst. *Applied Energy.* **88(10)**: 3313-7.

Liang, X.A., Dong W.B., Miao, X,J. and Dai, C.J. (2006). Production technology and influencing factors of microorganism grease. *Food Research and Developments.* **27(3)**: 46-47.

Lifka, J., Ondruschka, B. (2004). Einfluss des Stofftransportes auf die Herstellung von Biodiesel. *Chemie Ingenieur Technik.* **76(1-2)**: 168-171.

Liliana, R., Graziella, C.Z., Niccolo, B., Giulia, P., Natascia, B., Gimena, B. and Mario, R.T. (2009). Microalgae for oil: strain selection, induction of lipid synthesis and outdoor mass cultivation in a low-cost photobioreactor. *Biotechnology and Bioengineering.* **102**: 100-112.

Lin, R.H., Zhu, Y.Y. and Tavlarides, L.L. (2013). Mechanism and kinetics of thermal decomposition of biodiesel fuel. *Fuel.* **106**: 593-604.

Liu, F. and Zhang, Y. (2011). Controllable growth of multi-level tower ZnO for biodiesel production. *Ceramics International.* **37**: 3193-3202.

Liu, S.J., Yang, W.B. and Shi, A.H. (2000). Screening of the high lipid production strains and studies on its flask culture conditions. *Microbiology.* **27(2)**: 93-97.

Liu, X., He, H., Wang, Y., Zhu, S. and Piao, X. (2007). Tansesterification of soybean oil to biodiesel using SrO as a solid base catalyst. *Catalysis Communication.* **8**: 1107-1111.

Liu, X., He, H., Wang, Y., Zhu, S. and Piao, X. (2008a). Tansesterification of soybean oil to biodiesel using CaO as a solid base catalyst. *Fuel.* **87(2)**: 216-221.

Liu, X., Piao, X., Wang, Y. and Zhu, S. (2008b). Calcium methoxide as a solid base catalyst for the transesterificaton of soybean oil to biodiesel with methanol. *Fuel.* **22(2)**: 1313-1317.

Liu, Z.Y., Wang, G.C. and Zhou, B.C. (2007). Effect of iron on growth and lipid accumulation in *Chlorella vulgaris*. *Bioresources Technology.* **99**: 4717-4722.

Lois, E. (2007). Difinition of biodiesel. *Fuel.* **86(7-8)**: 1212-1213.

López, D.E., Goodwin Jr., J.G., Bruce, D.A. and Furuta, S. (2008). Esterification and transesterification using modified-zirconia catalysts. *Applied Catalysis, A: General.* **339**: 76-83.

López, D.E., Goodwin, J.G. Jr., Bruce, D.A., Lotero, E., (2005). Transesterification of triacetin with methanol on solid acid and base catalysts. *Applied Catalysis A: General.* **295(2)**: 97-105.

López, D.E., Goodwin, J.G., Jr., Bruce, D.A., (2007). Transesterification of triacetin with methanol on Nafion® acid resins. *Journal of Catalysis.* **245(2):** 381-391.

Lótero, E., Goodwin, J.G.Jr., Bruce, D.A., Suwannakarn, K., Liu, Y. and Lopez, D.E. (2006). The catalysis of biodiesel synthesis. *Catalysis.* **19**: 41-83.

Lótero, E., Liu, Y., Lopez, D.E., Suwannakarn, K., Bruce, D.A. and Goodwin Jr., J.G. (2005). Synthesis of Biodiesel via Acid Catalysis. *Industrial & Engineering Chemistry Research*. **44**: 5353-5363.

Ma, F. and Hanna, H.A. (1999). Biodiesel production: a review. *Bioresources Technology*. **70**: 1-15.

Ma, F.R., Clements, L.D. and Hanna, M.A. (1998). Biodiesel fuel from animal fat. Ancillary studies on transesterification of beef tallow. *Industrial and Engineering Chemistry Research*. **37**: 3768-3771.

Makkar, H.P.S. and Becker, K., (2009). *Jatropha curcas*, a promising crop for generation of biodiesel and value-added coproducts. *European Journal of Lipid Science and Technology*. **111**: 773-787.

Mandal S. and Mallick N. (2009). Microalga *Scenedesmus obliquus* as a potential source for biodiesel production. *Applied Biochemistry and Biotechnology*. **84**: 281-291.

Mandeep, K. and Amjad, A. (2014). Potassium fluoride impregnated CaO/NiO: an efficient heterogeneous catalyst for transesterification of waste cottonseed oil. *European Journal of Lipid Science and Technology*. **116**: 80-88.

Marchetti, J.M., Miguel, V.U. and Errazu, A.F. (2007). Possible methods for biodiesel production. *Renewable and Sustainable Energy Reviews.* **11**:1300-1311.

Margandan B., Mari V. and Andrews, N.G. (2013). Transesterification of jatropha oil over ceria-impregnated ZSM-5 for the production of bio-diesel. *Bulletin of the Korean Chemical Society*. **34(10)**, 3059-3064.

Martín M.I.E.G. (2014). URL: http://egon.cheme.cmu.edu/Papers/MartinGrossmannBiodiesel%20production%20algae.pdf (Accessed June, 2014).

Mat Yasin, M.H., Yusaf, T., Mamat, R. and Fitri Yusop, A. (2014). Characterization of a diesel engine operating with a small proportion of methanol as a fuel additive in biodiesel blend. *Applied Energy*. **114**: 865-873.

Mata T.M., Martins, A.A. and Caetano N.S. (2010). Microalgae for biodiesel production and other applications: A review. *Renewable Sustainable Energy Reviews.* **14**: 217-232.

McNeff, C.V., McNeff, L.C., Yan, B., Nowlan, D.T., Rasmussen, M., Gyberg, A.E., et al. (2008). A continuous catalytic system for biodiesel production. *Applied Catalysis A: General.* **343**: 39-48.

Meher, L.C., Sagar, D.V. and Naik, S.N. (2006). Technical aspects of biodiesel production by transesterification-a review. *Renewable and Sustainable Energy Reviews.* **10(3)**: 248-268.

Metting, F. (1996). Biodiversity and application of microalgae. *Journal of Industrial Microbiology and Biotechnology*. **17**: 477-489.

Miao, X.L. and Wu, Q.Y. (2006). Biodiesel production from heterotrophic microalgal oil. *Bioresources Technology.* **97**: 841-846.

Modi, M.K., Reddy, J.R.C., Rao, B. and Prasad, R.B.N. (2007). Lipase-mediated conversion of vegetable oils into biodiesel using ethyl acetate as acyl acceptor. *Bioresources Technology.* **98**: 1260-1264.

Moser, B.R., Haas, M.J., Winkler, J.K., Jackson, M.A., Erhan, S.Z. and List, G.R. (2007). Evaluation of partially hydrogenated methyl esters of soybean oil as biodiesel. *European Journal of Lipid Sciences and Technology.* **109**: 17-24.

Muniyappa, P.R., Brammer, S.C. and Noureddini, H. (1996). Improved conversion of plant oils and animal fats into biodiesel and co-product. *Bioresources Technology.* **56**: 19-24.

Nautiyal, P., Subramanian, K.A. and Dastidar, M.G. (2014). Production and characterization of biodiesel from algae. *Fuel Processing Technology.* **120**: 79-88.

Ngamcharussrivichai, C., Totarat, P. and Bunyakiat, K. (2008). Ca and Zn mixed oxide as a heterogeneous base catalyst for transesterification of palm kernel oil. *Applied Catalysis A: General*, **341**: 77-85.

No, S.Y. (2011). Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: A review. *Renewable and Sustainable Energy Reviews.* **15**: 131-149.

Noureddini, H., Gao, X. and Philkana, R.S. (2005). Immobilized Pseudomonas cepacia *lipase* for biodiesel fuel production from soybean oil. *Bioresources Technology.* **96(7)**: 769-777.

Ofori-Boateng, C., Lee, K.T. and Lim, J.K. (2012). Comparative exergy analyses of Jatropha curcus oil extraction methods; solvent and mechanical extraction processes. *Energy Conversion and Management.* **55**: 164-171.

Ohi, A., Aoyama, H., Kato, A. and Yamaoka, M. (1983). Fatty acid ester from palm oil as diesel fuel. *Nenryo Kyokaishi.* **62**: 24-31.

Oliveira, D. and Oliveira, J.V. (2011). Enzymatic alcoholysis of palm kernel oil in n-hexane and $SCCO_2$. *Journal of Supercritical Fluids.* **19**: 141-148.

Oliveira, L.S., Franca, A.S., Camargos, R.R.S. and Ferraz, V.P. (2008). Coffee oil as a potential feedstock for biodiesel production. *Bioresources Technology.* **99(8)**: 3244-3250.

Ondrey, G. (2004). Biodiesel production using a heterogeneous catalyst. *Chemical Engineering.* **111(11)**: p13.

Ono, Y. and Baba, T. (1997). Selective reactions over solid base catalysts. *Catalysis Today.* **38**: 321-337.

Openshaw, K. (2000). A review of *Jatropha curcas* oil plant of unfillfilled promise. *Biomass and Bioenergy.* **19 (1)**: 1-15.

Parawira, W. (2009). Biotechnological production of biodiesel fuel using biocatalysed transesterification: a Review. *Critical Reviews in Biotechnology.* **29**: 82-93.

Parawira, W. (2010). Biodiesel production from *Jatropha curcas*: a review. *Scientific Research and Essays.* **5(14)**: 1796-1808.

Park, Y.M., Lee, D.W., Kim, D.K., Lee, J.S. and Lee, K.Y. (2008). The heterogeneous catalyst system for the continuous conversion of free fatty acids in used vegetable oils for the production of biodiesel. *Catalysis Today.* **131(1-4)**: 238-243.

Park, Y.M., Lee, J.Y., Chung, S.H., Park, I.S., Lee, S.Y., Kim D.K. et al. (2010). Esterification of used vegetable oils using the heterogeneous WO_3/ZrO_2 catalyst for production of biodiesel. *Bioresources Technology.* **101(1)**: S59-S61.

Parthasarathi, B., Michael, R., Hegde, M.S. and Kamath, P.V. (2000). Thermal behaviour of hydroxides, hydroxysalts and hydrotalcites. *Bulletin Materials Science.* **23**: 141-145.

Patil, P., Reddy, H., Muppaneni, T., Ponnusamy, S., Sun, Y.Q., Dailey, P., Cooke, P., Patil, U., Deng, S.G. (2013). Optimization of microwave-enhanced methanolysis of algal biomass to biodiesel under temperature controlled conditions. *Bioresources Technology*. **137**: 278-285.

Patil, P.D., Gnaneswar, V. and Deng, S.G. (2009). Biodiesel production from *Jatropha curcus*, waste cooking and *Camelina sativa* oils. *Industrial Engineering Chemical Research.* **48**: 10850-10856.

Patil, P.D., Gude, V.G., Mannarswamy, A., Deng, S.G., Cooke, P., McGee, S.M., Rhodes, I. and Nirmalakhandan, N. (2011). Optimization of direct conversion of wet algae to biodiesel under supercritical methanol conditions. *Bioresources Technology.* **102(1)**: 118-122.

Peltier, E., Allada, R., Navrotsky, A. and Sparks, D.L. (2006). Nickel solubility and precipitation in soils: a thermodynamic study. *Clays and Clay Minerals.* **54**: 153-164.

Pinzi, S., Garcia, I.L., Lopez-Gimenez, F.J., Luque de Castro, M.D., Dorado, G. and Dorado, M.P. (2009). The ideal vegetable oil-based biodiesel composition: a review of social, economical and technical impacts. *Energy and Fuels.* **23**: 2325-2341.

Prakash, B. (2010). Botryococcus braunii and Spirogyra are High Biodiesel Producing Algae Species. *International Journal of Chemical Engineering Research.* **2(3)**: 259-267.

Promotion, C.f.J. (2014). algae biodiesel: commercialization, research & business platform; 2014. URL:http://www.jatrophaworld.org/global_algae_biodiesel_world_2012_93.html (Accessed April, 2014).

Rabiah Nizah M.F., Taufiq-Yap, Y.H., Rashid, U., Teo, S.H. and Hussein, M.Z. (2014). Production of biodiesel from non-edible *Jatropha curcas* oil via transesterification using Nd_2O_3–La_2O_3 catalyst. *Energy Conversion and Management.* **88**: 1257-1262.

Rabiah Nizah, M.F., Taufiq-Yap, Y.H. and Hussein, M.Z. (2013). Production of biodiesel from non-edible *Jatropha curcas* oil via transesterification using Nd_2O_3–La_2O_3 catalyst. *Advanced Materials Research.* **620**: 335-339.

Ramachandran, K., Suganya, T., Nagendra Gandhi, N. and Renganathan, S. (2013). Recent developments for biodiesel production by ultrasonic assist transesterification using different heterogeneous catalyst: A review. *Renewable Sustainable Energy Reviews.* **22**: 410-418.

Ramadhas, A.S., Jayaraj, S. and Muraleedharan, C. (2005). Biodiesel production from high FFA rubber seed oil. *Fuel*. **84**: 335-340.

Rashid, U., Anwar, F. and Arif, M. (2009). Optimization of base catalytic methanolysis of sunflower (*Helianthus annuus*) seed oil for biodiesel production by using response surface methodology. *Industrial and Engineering Chemistry Research.* **48**: 1719-1726.

Rashid, U., Anwar, F., Moser Bryan, R. and Ashraf, S. (2008). Production of sunflower oil methyl ester by optimized alkali-catalyzed methanolysis. *Biomass and Bioenergy.* **32**: 1202-1205.

Reddy, C., Reddy, V., Oshel, R. and Verkade, J.G. (2006). Room-temperature conversion of soybean oil and poultry fat to biodiesel catalyzed by nanosrystalline calcium oxides. *Energy and Fuels.* **20 (3)**: 1310-1314.

Reddy, H.K, Muppaneni, T., Patil, P.D., Ponnusamy, S., Cooke, P. Schaub, T. and Deng, S.G. (2014). Direct conversion of wet algae to crude biodiesel under supercritical ethanol conditions. *Fuel.* **115**: 720-726.

Reid, E.E. (1911). Studies in esterification. IV. The interdependence of limits as exemplified in the transformation of esters. *American Chemistry Journal.* **45**: 479-516.

Reijnders L. (2008). Do biofuels from microalgae beat biofuels from terrestrial plants? *Trends in Biotechnology*. **26(7)**: 349-350.

Reyes, Y., Chenard,G., Aranda, D., Mesquita, C., Fortes, M., Joa˜o, R., Bacellar, L. (2012). Biodiesel production by hydroesterification of microalgal biomass using heterogeneous catalyst. *Natural Sciences.* **4**: 778-783.

Ríos, S.D., Castaneda, J. Torras, C., Farriol, X. and Salvadó, J. (2013). Lipid extraction methods from microalgal biomass harvested by two different paths: Screening studies toward biodiesel production. *Bioresources Technology*. **133**: 378-388.

Robles-Medina, A., Gonzales-Moreno, P.A., Esteban-Cerdan, L. and Molina-Grima, E. (2009). Biocatalysis: towards ever greener biodiesel production. *Biotechnology Advances.* **27**: 398-408.

Ross, A.B. Jones, J.M. Kubacki, M.L. and Bridgeman, T. (2008). Classification of macroalgae as fuel and its thermochemical behavior. *Bioresources Technology.* **99**: 6494-6504.

Royon, D. and Daz, M. (2007), Enzymatic production of biodiesel from cotton seed oil using t-butanol as a solvent. *Bioresources Technology.* **98**: 648-653.

Saka, S., Kusdiana, D. and Minami, E. (2006). Non-catalytic biodiesel fuel production with supercritical methanol technologies. *Journal of Scientific and Industrial Research.* **65(5)**: 420-425.

Sani, Y.M., Daud, W.M.A.W. and Aziz, A.R.A. (2013). Solid acid-catalyzed biodiesel production from microalgal oil-the dual advantage. *Journal of Environmental Chemical Engineering.* **1**: 113-121.

Santos, A.M., Janssen, M., Lamers, P.P., Evers, W.A.C. and Wijffels, R.H. (2012). Growth of oil accumulating microalga *Neochloris oleoabundans* under alkaline–saline conditions. . *Bioresources Technology*. **104**: 593-599.

Sarin, M., Arora, R., Singh, N.P., Sarin, R. and Malhotra, R.K. (2010). Blends of biodiesels synthesized from non-edible and edible oils: influence on the OS (oxidation stability). *Energy.* **35**: 3449-3453.

Sarin, R., Sharma, M., Sinharay, S. and Malhotra, R.K. (2007). Jatropha-Palm biodiesel blends:an optimum mix for Asia. *Fuel.* **86**: 1365-1371.

Sarkar, D., Tikku, S., Thapar, V., Srinivasa, R.S. and Khilar, K.C. (2011). Formation of zinc oxide nanoparticles of different shapes in water-in-oil microemulsion. *Colloids Surfaces A: Physicochemical and Engineering Aspects.* **381**: 123-129.

Schwab, A.W. Dykstra, G.J., Selke, E., Sorenson, S.C. and Pryde, E.H. (1988). Diesel fuel from thermal decomposition of soybean oil. *Journal of the American Oil Chemist's Society.* **65**: 1978-1786.

Serio, M. D., Tesser, R., Pengmei, L. and Santacesaria, E., 2008. Heterogeneous catalysts for biodiesel production. *Energy and Fuels.* **22**: 207-217.

Seshu Babu, N., Rekha, S., Sai Prasad, P.S. and Lingaiah, N. (2008). Room temperature transesterification of edible and nonedible oils using a heterogeneous strong basic Mg/La catalyst. *Energy and Fuels*. **22(3)**: 1965-1971.

Shah, S., Sharma, S. and Gupta, M.N., (2005). Extraction of oil from J*atropha curcas* L. seed kernels by combination of ultrasonication and aqueous enzymatic oil extraction. *Bioresources technology.* **96**: 121-123.

Shajaratun Nur, Z.A., Taufiq-Yap, Y.H., Rabiah Nizah, M.F., Teo, S.H., Syazwani, O.N. and Islam, A. (2014). Production of biodiesel from palm oil using modified Malaysian natural dolomites. *Energy Conversion and Management.* **78**: 738-744.

Shi, H. and Bao, Z., (2008). Direct preparation of biodiesel from rapeseed oil leached by two-phase solvent extraction. *Bioresources Technology*. **99**: 9025-9028.

Shibasaki-Kitakawa, N., Honda, H., Kuribayashi, H., Toda, T., Fukumura, T. and Yonemoto, T. (2007). Biodiesel production using anionic ion-exchange resin as heterogeneous catalyst. *Bioresources Technology*. **98(2)**: 416-421.

Shimada, Y., Watanabe, Y., Samukawa, T., Sugihara, A., Noda, H., Fukuda, H. and Tominaga, Y. (1999). Conversion of vegetable oil to biodiesel using immobilized Candida Antarctica lipase. *Journal of the American Oil Chemist's Society*. **76**: 789-793.

Singh, A.K. and Fernando, S.D. (2008). Transesterification of soybean oil using heterogeneous catalysts. *Energy and Fuels.* **22**: 2067-2069.

Singh, A.K. and Fernando, S.D. (2007). Reaction kinetics of soybean oil transesterification using heterogeneous metal oxide catalysts. *Chemical Engineering and Technology*, **30**: 1716-1720.

Sisipim, L., Thikumporn, N., Kunchana, B. and Chawalit, N. (2013). Mixed oxides of Ca, Mg and Zn as heterogeneous catalysts for synthesis of palm kernel oil methyl esters. *Journal Chemical Engineering.* **225**: 616-624.

Soares Dias, A.P., Bernardo, J., Felizardo, P. and Neiva Correia, M.J. (2012). Biodiesel production over thermal activated cerium modified Mg-Al hydrotalciyes. *Energy*. **41**: 344-353.

Solovchenko, A.E., Khozin-Goldberg, I., Didi-Cohen, S., Cohen, Z., Merzlyak, M.N. (2008). Effects of light intensity and nitrogen starvation on growth, total fatty acids and arachidonic acid in the green microalga *Parietochloris incisa*. *Journal of Applied Phycology.* **20**: 245-251.

Son, S.M. and Kusakabe, K. (2011). Transesterification of sunflower oil in a countercurrent trickle-bed reactor packed with a CaO catalyst. *Chemical Engineering and Processing: Process Intensification*. **50(7)**: 650-654.

Son, S.M., Kusakabe, K. and Guan, G. (2010). Biodiesel synthesis and properties from sunflower and waste cooking oils using CaO catalyst under reflux condition. *Journal of Applied Sciences.* **10(24)**: 3191-3198.

Song, D., Fu, J. and Shi, D. (2008). Exploitation of oil-bearing microalgae for biodiesel. *Chinese Journal of biotechnology*. **24(3)**: 341-348.

Stavarache, C., Vinatoru, M., Nishimura, R. and Maed, Y. (2005). Fatty acids methyl esters from vegetable oil by mean of ultrasonic energy. *Utrasonic Sonochemistry.* **12**: 367-372.

Stephens, E., Ross, I.L., King, Z., Mussgnug, J.H., Kruse, O., Posten, C., Borowitzka, M.A. and Hankamer, B. (2010). An economic and technical evaluation of microalgal biofuels. *Nature Biotechnology*. **28**: 126-128.

Stern, R., Hillion, G., Rouxel, J.J. and Leporq, S. (1999). Process for the production of esters from vegetable oils or animal oils and alcohol. US Patent 5908946.

Steven Lim, and Lee K.T. (2013). Process intensification for biodiesel production from *Jatropha curcas* L. seeds: supercritical reactive extraction process parameters study. *Applied Energy.* **103**: 712-720.

Stucki, S., Vogel, F., Ludwig, C., Haiduc, A.G. and Brandenberger, M. (2009). Catalystic gasification of algae in supercritical water for biofuel production and carbon capture. *Energy and Environmental Science.* **2**: 535-541.

Suppes, G.J., Dasari, M.A., Doskocil, E.J., Mankidy, P.J. and Goff, M.J. (2004). Transesterification of soybean oil with zeolite and metal catalysts. *Applied Catalysis A: General.* **257**: 213-223.

Szentmihalyi, K., Vinklera, P., Lakatosa, B., Illesb, V. and Thenc, M. (2002). Rose hip (*Rosa canica* L.) oil obtained from waste hip seeds by different extraction method. *Bioresources Technology.*82: 195-201.

Szewczyk, K.W., Pilarek, M., Tymosiewicz, R. and Pec, K. (2003). The effect of fatty acid chain length on the kinetics of enzymatic alcoholysis. *Przemyst Chemiczny.* **82(8-9)**: 1100-1103.

Tamarys H. and Wei W. and Bo H. (2010). Oil Accumulation via heterotrophic/mixotrophic *Chlorella protothecoides*. *Applied Biochemistry and Biotechnology.* **162**: 1978-1995.

Tan, H.T., Lee, K.T. and Mohamed, A.R. (2010). Second-generation bio-ethanol (SGB) from Malaysia palm empty fruit bunch: Energy and exergy analyses. *Bioresources Technology.* **101**: 5719-5727.

Tan, K.T., Lee, K.T. and Mohamed, A.R. (2011). Potential of waste palm cooking oil for catalyst biodiesel production. *Energy.* **36**: 2085-2088.

Tanabe, K. and Hoelderich, W.F. (1999). New solid acids and bases. *Applied Catalysis A: General.* **181**: 399-434.

Tang, H.Y., Nadia Abunasser, M.E.D., Garcia, M.C., Simon Ng, K.Y. and Salley, S.O. (2011) Potential of microalgae oil from *Dunaliella tertiolecta* as a feedstock for biodiesel. *Applied Energy.* **88**: 3324-3330.

Tang, Z., Wang, L. and Yang, J. (2007). Transesterification of the crude *Jatropha curcas* L. oil catalyzed by micro-NaOH in supercritical and subcritical methanol. *European Journal of Lipid Science and Technology.* **109**: 585-590.

Tapanes, N.C.O., Aranda, D.A.G., Carneiro, J.W.M. and Antunes, O.A.C. (2008). Transesterification of *Jatropha curcas* oil glycerides: theoretical and experimental studies of biodiesel reaction. Fuel, **87**, 2286-2295.

Taufiq-Yap, Y.H., Lee, H.V., Hussein, M.Z. and Yunus, R. (2011a) Calcium-based mixed oxide catalysts for methanolysis of Jatropha curcus oil to biodiesel. *Biomass & Bioenergy*. **35**: 827-834.

Taufiq-Yap, Y.H., Lee, H.V., Yunus, R. and Juan, J.C. (2011b). Transesterification of non-edible *Jatropha curcas* oil to biodiesel using binary Ca-Mg mixed oxide catalyst: effect of stoichiometric composition . *Chemical Engineering Journal.* **178**: 342-347.

Taufiq-Yap, Y.H., Sivasangar, S. and Salmiaton, A. (2012). Enhancement of hydrogen production by secondary metal oxide dopants on NiO/CaO material for gasification of empty palm fruit bunches. *Energy.* **47(1)**: 158-165.

Teo, S.H., Taufiq-Yap, Y.H. and Ng, F.L. (2014). Alumina supported/ unsupported mixed oxides of Ca and Mg as heterogeneous catalysts for transesterification of Nannochloropsis sp. microalga's oil. *Energy Conversion and Management.* **88**: 1193-1199.

Thitsartarn, W. and Kawi, S. (2011). An active and stable CaO-CeO_2 catalysts for transesterification of oil to biodiesel. *Green Chemistry.* **13**: 3423-3430.

Timonthy, R. and Timon, H. (2012). Fatty acid methyl esters in B100 biodiesel by gas chromatography (modified European Standard of EN 14103). Shelton, CT USA: PerkinElmer, Inc.

Titipong, I. and Ajay, K.D. (2014). Biodiesel from vegetable oils. *Renewable Sustainable Energy Reviews.* **31**: 446-471.

Todaka, M., Kowhakul, W., Masamoto, H., Shigematsu, M. and Onwana-Agyeman, S. (2013). Thermal decomposition of biodiesel fuels produced from rapeseed, jatropha, and coffee oils with different alcohols. *Journal of Thermal Analysis and Calorimetry.* **113**: 1355-1361.

Tran, N.H., Bartlett, J.R., Kannangara, G.S.K., Milev, A.S., Volk, H. and Wilson, M.A. (2010). Catalytic upgrading of biorefinery oil from micro-algae. *Fuel.* **89**: 265-274.

Tsukahara K, Sawayama S. (2005). Liquid fuel production using microalgae. *Journal of the Japan Petroleum Institute.* **48(5)**: 251-259.

Umdu, E.S., Tuncer, M. and Seker, E. (2009). Transesterification of *Nannochloropsis oculata* microalga's lipid to biodiesel on Al_2O_3 supported CaO and MgO catalysts. *Bioresources Technology.* **100**, 2828-2831.

Van Gerpen, J. (2005). Biodiesel processing and production. *Fuel Processing Technology.* **86(10)**: 1097-1107.

Van Gerpen, J., Shanks, B. and Pruszko, R. (2004). National Renewable Energy Laboratory Biodiesel Analytical Methods, p 95.

Vasudevan, P.T. and Briggs, M. (2008). Biodiesel production-current state of the art and challenges. *Journal of Industrial Microbiology and Biotechnology.* **35**: 421-430.

Verghaa, V. and Truterb, P. (2005). Biodegradable polymers by reactive blending transesterification of thermoplastic starch with poly(vinyl acetate) and poly(vinyl acetate-co-butyl acrylate). *European Polymer Journal.* **41**: 715-726.

Vyas, A.P., Subrahmanyam, N. and Patel, P.A. (2009). Production of biodiesel through esterification of Jatropha oil using KNO_3/Al_2O_3 solid catalyst. *Fuel*. **88**: 625-628.

Vyas, A.P., Verma, J.L. and Subrahmanyam, N. (2010). A review on FAME production processes. *Fuel.* **8**: 1-9.

Wang, H., Gao, L.L., Chen, L. Guo, F.J. and Liu, T.Z. (2013). Integration process of biodiesel production from filamentous oleaginous microalgae *Tribonema minus*. *Bioresources Technology*. **142**: 39-44.

Wang, Y., Wu, H. and Zong, M.H. (2008). Improvement of biodiesel production by lopozyme TL IM-catalyzed methanolysis using response surface methodology and acyl migration enhancer. *Bioresources Technology.* **99**: 7232-7237.

Wang, Y.D., Al-Shemmeri, T., Eames, P., McMullan, J., Hewitt, N., Huang, Y., et al. (2006). An experimental investigation of the performance and gaseous exhaust emission of a diesel engine using blends of a vegetable oil. *Applied Thermal Engineering.* **26**: 1684-1691.

Warabi, Y., Kusdiana, D. and Saka, S. (2004a). Biodiesel fuel from vegetable oil by various supercritical *alcohols. Applied Biochemistry and Biotechnology.* **113-116**: 793-801.

Warabi, Y., Kusdiana, D. and Saka, S. (2004b). Reactivity of triglycerides and fatty acids of rapeseed oil in supercritical alcohols. *Bioresources Technology.* **91(3)**: 283-287.

Watanabe, Y., Pinsirodom, P., Nagao, T., Kobayashi, T., Nishida, M., Takagi, Y. and Shimada, Y. (2005). Production of FAME from acid *oil* model using immobilized Candida antarctica lipase. *Journal of the American Oil Chemist's Society.* **82**: 825-831.

Watanabe, Y., Shimada, Y., Sugihara, A. and Tominaga, Y. (2001). Enzymatic conversion of waste edible oil to biodiesel fuel in a fixed-bed bioreactor. *Journal of the American Oil Chemist's Society.* **78**: 703-707.

Weldy, C.S. and Huesemann, M. (2010). Lipid production by *Dunaliella salina* in batch culture: effects of nitrogen limitation and light intensity. U.S. Department of Energy *Journal of Undergraduate Research*. 115-122. Ref Type: Magazine Article.

Wen, Z., Yu, X., Tu, S.T., Yan, J. and Dahlquist, E. (2010). Biodiesel production from waste cooking oil catalyzed by TiO_2–MgO mixed oxides. *Bioresources Technology.* **101**: 9570-9576.

Wen, Z.Y. and Michael, B.J. (2009). Microalgae as a feedstock for biofuel production. Virginia Cooperative Extension Publication 442-886. Available at http://pubs.ext.vt.edu/442-886/. (Accessed April 2014).

West, A.R. (2007). Solid State Chemistry and Its Applications, Wiley India Pvt. Ltd.

Xiong, W., Li, X.F., Xiang, J.Y. and Wu, Q.Y. (2008). High-density fermentation of microalga *Chlorella protothecoides* in bioreactor for microbio-diesel production. *Applied Biochemistry and Biotechnology.* **78**: 29-36.

Xu, H., Miao, X.L. and Wu, Q.Y. (2006). High quality biodiesel production from a microalga *Chlorella protothecoides* by heterotrophic growth in fermenters. *Journal of Biotechnology.* **126**: 499-507.

Xu, R. and Mi, Y., (2011). Simplifying the process of microalgal biodiesel production through in situ transesterification technology. *Journal of the American Oil Chemists' Society.* **88(1)**: 91-99.

Xue, J., Tinkler, J.H. and Diechmann, R. (2004). Influence of impurities on the oxygen activity dependent variation of the oxygen content of a commercial, CaO-doped ZrO_2. *Solid State Ionics,* **166(1-2)**: 199-205.

Yan, S.L., Kim, M.H., Steven, O.S. and Simon, K.Y.N. (2009). Oil transesterification over calcium oxides modified with lanthanum. *Applied Catalysis A: General.* **360**: 163-170.

Yang, Z.Q. and Xie, W.L. (2007). Soybean oil transesterification over zinc oxide modified with alkali earth metals. *Fuel Processing Technology*. **88**: 631-638.

Yee, K.F., Wu, J.C.S. and Lee, K.T. (2011). A green catalyst for biodiesel production from *Jatropha* oil: optimization study. *Biomass and Bioenergy.* **35**: 1739-1746.

Yoosuk, B., Krasae, P., Puttasawat, B., Udomsap, P., Viriya-empikul, N. and Faungnawakij, K. (2010*).* Magnesium modified strontium as a solid base catalyst for transesterification of palm olein. *Journal Chemical Engineering.* **162**: 58-66.

Yusaf Al-Juboori, T. (2014). Alternative methods of microorganism disruption for agricultural applications. *Applied Energy.* **114**: 909-923.

Zabeti, M., Daud, W.M.A.W. and Aroua, M.K. (2009). Activity of solid catalysts for biodiesel production: a review. *Fuel Processing Technology.* **90**: 770-777.

Zhang, Y., Dube, M.A., McLean, D.D. and Kates, M. (2003a). Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis. *Bioresources Technology*. **90**: 229-240.

Zhang, Y., Dube, M.A., McLean, D.D., Kates, M., (2003b). Biodiesel production from waste cooking oil: 1. Process design and technological assessment. *Bioresources Technology*. **89**: 1-16.

Zheng, S., Kates, M., Dube, M.A. and McLean, D.D. (2006). Acid-catalyzed production of biodiesel from waste frying oil. *Biomass and Bioenergy*. **30(3)**: 267-272.

Zhou, X.P., Ge, H.M., Xia, L., Zhang, D.L. and Hu, C.X. (2013). Evaluation of oil-producing algae as potential biodiesel feedstock. *Bioresources Technology*. **134**: 24-29.

Zhu, H., Wu, Z., Chen, Y., Zhang, P., Duan, S., Liu, X. and Mao, Z. (2006). Preparation of biodiesel catalyzed by solid super base of calcium oxide and its refining process. *Chinese Journal of Catalysis*. **27**: 391-396.

Zu. Y.H., Liu, G., Wang. Z.L., Shi, J.H., Zhang. M. and Zhang, W.X. (2010). CaO supported on porous carbon as highly efficient heterogeneous catalysts for transesterification of triacetin with methanol. *Energy and Fuels*. **24**: 3810-3816.