SYNTHESIS OF CATALYST FROM EGGSHELL AND PERNA *V.* SHELL FOR BIOLUBRICANT PRODUCTION

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MASTER OF SCIENCE

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Pada masa ini, isu-isu pemuliharaan alam sekitar telah meningkat disebabkan oleh penggunaan minyak pelincir yang berasaskan minyak sintetik dan mineral secara meluas. Penggunaan secara terus minyak sayuran sebagai minyak asas minyak pelincir untuk mengelakan isu-isu alam sekitar tidak efisen kerana kestabilan pengoksidaan, haba dan hidrolitik minyak sayuran yang lemah.Transesterifikasi digunakan secara meluas di industri untuk menangani batasan ini. Dalam usaha untuk menangani masalah yang timbul dengan penggunaan pemangkin homogen, kajian kini tertumpu pemangkin heterogen iaitu kalsium oksida daripada sisa kulit telur dan *Perna V.* Prestasi pemangkin ini telah diuji. Pemangkin daripada kulit telur dan Perna .v telah disediakan dan diuji untuk mengenalpasti suhu penguraian, morfologi permukaan, luas permukaan dan corak pembelauan X-Ray dan komposisi unsur pemangkin. Dua langkah tindak balas transesterifikasi telah dikaji untuk menukar minyak jarak ke dalam produk akhir iaitu minyak jarak trimethylolpropane triester. Produk perantaraan tertinggi iaitu minyak jarak methyl ester yang tertinggi diperolehi pada masa reaksi 2 jam, metanol kepada nisbah minyak 6: 1, suhu operasi 65° dan 2wt /% berat pemangkin. Pemangkin berkesan untuk tindak balas transesterifikasi pemangkin pertama adalah kalium yang dihamilkan *Perna V.* Pemangkin kulit *Perna V.*bersama kalium memberi hasil 92.2%. Manakala bagi keadaan operasi optimum bagi tindak balas transesterification pemangkin kedua antara minyak kastor methyl ester dan trimethylolpropane berada di 120°C, masa tindak balas 3 jam dengan 3wt / wt% daripada kepekatan pemangkin dan 4: 1 TMP untuk nisbah molar. Pemangkin terbaik untuk tindak balas transesterification kedua adalah kalium berubat telur pemangkin dengan 72.4% daripada komposisi triester. Bagi kedua-dua tindak balas transesterifikasi, pemangking cengkerang yang telah dihamilkan adalah lebih baik daripada cengkerang yang tidak dihamilkan kerana terdapat banyak tempat aktif untuk menpercepatkan reaksi. Ester trimethlolpropane yang dihasilkan sejajar dengan piawaian minyak pelincir untuk kegunaan hydrolic.

ABSTRACT

Currently, environment conservation issues had been rising due to the extensive usage of mineral and synthetic oil based lubricants. The direct application of vegetable oil as biolubricant base oil to overcome these environmental concerns had some drawbacks due to poor oxidation, thermal and hydrolytic stability of the vegetable oil. Catalytic transesterification is widely used in industry to tackle these limitations. In order to tackle the problems arise with the usage of existing homogeneous and heterogeneous catalyst, this study focused on employment of non- and potassium hydroxide impregnated heterogeneous calcium oxide catalyst from waste egg and *Perna V.* shell catalysts. The potential of impregnated waste based catalyst in the synthesis of biolubricant still have not been explored. The performances of these catalysts were being tested. The non- and impregnated egg and *Perna V.* catalysts were prepared and the decomposition temperature, surface morphology, surface area and X-Ray diffraction patterns and elemental composition of the catalysts were investigated. The two steps of transesterification reaction of castor oil into final product of castor oil trimethylolpropane triester were researched. The production of biolubricant consists of two catalytic transesterification reactions in series with castor oil methyl ester as intermediate product. The highest intermediate product, castor oil methyl ester were obtained at reaction time of 2 hours, methanol to oil ratio of 6:1, operation temperature of 65° and 2wt/wt% of catalyst loading. The effective catalyst for this reaction was potassium impregnated *Perna V.* shell catalyst with castor oil methyl ester yield of 92.2%. The optimum operation conditions for second catalytic transesterification reaction between castor oil methyl ester and trimethylolpropane was at 120°C, reaction time of 3 hours with 3wt/wt% of catalyst concentration and 4:1trimethylolpropane to castor oil methyl ester molar ratio. The best catalyst for the second transesterification reaction was potassium impregnated eggshell catalyst with 71.4% of triester composition. For both the reaction, the impregnated catalyst performed better than the non-impregnated catalysts due to the presence of enhanced active sites for the transesterification to take place. The produced trimethylolpropane esters followed the biolubricant standards for hydraulic purposes.

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LIST OF SYMBOLS

°C	Degree Celcius
h	Hour
min	Minute
%	Percentage

LIST OF ABBREVIATIONS

BDL	Below Detectable Level
BET	Brunauer-Emmet-Teller
COME	Castor oil methyl ester
CaO	Calcium oxide
COTT	Castor oil trimethylolpropane triester
CCD	Central composite design
FFA	Free fatty acid
FTIR	Fourier transform infra-red spectrometry
GC-FID	Gas chromatography – flame ionization detector
GC-MS	Gas chromatography - mass spectrometry
ICEPS	Impregnated chicken egg and *Perna V.* shell catalysts
IES	Impregnated egg shell catalyst
IPS	Impregnated *Perna V.* shell catalyst
ISO VG	International Standard Organization Viscosity Grade
KOH	Potassium hydroxide
SEM	Scanning electron microscopy
TGA-DTA	Thermogravimetric and differential thermal analysis
TMP	Trimethylolpropane
XRD	X-Ray diffraction
XRF	X-Ray fluorescence

REFERENCES

Adhvaryu, A., & Erhan, S. Z. (2002). Epoxidized soybean oil as a potential source of high-temperature lubricants. *Industrial Crops and Products, 15*(2002), 247-254.

Akpan, U. G., Jimoh, A., & Mohammed, A. D. (2006). Extraction, characterization and modification of castor seed oil. *Leonardo Journal of Sciences, 8*,43-52.

Alam, Z., Muyibi, S. A., & Kamaldin, N. (2008). Production of activated carbon from oil palm empty fruit bunches for removal of zinc. *Proc Int Water Technol Con, Aixeandria Egypt*, 373-382.

Albuquerque, M. C. G., Jimenez-Urbistondo, I., Santamaria-Gonzalez, J., Merida-Robles, J. M., Moreno-Tost, R., Rodriguez-Castellon, E., Jimenez-Lopez, A., Azevedo, D. C. S., Cavalcante Jr, C. L., & Maireles-Torres, P. (2008). CaO supported on mesoporous silicas as basic catalysts for transesterification reactions. *Applied Catalysis A: General, 334*(2008), 35-43.

Alptekin, A., & Canakci, M. (2008). Determination of the density and the viscosities of biodiesel-diesel fuel blends. *Renewable Energy, 33*(2008), 2623-2630.

Amdebrhan, B. T., Damtew, L., Tesfay, D., Endris, H., & Tekeste, G. (2015). Production of biolubricant from castor (ricinus) oil. *Int. Journal of Engineering Innovation & Research, 4*(5), 737-741.

Arbain, N. H., & Salimon, J. (2010). Synthesis and characterization of ester trimethylolpropane based *Jatropha Curcas* oil as biolubricant base stocks. *Journal of Science and Technology*, 47-58.

American Society for Testing and Materials: Annual Books of ASTM Standards: Petroleum Products, Lubricants and Fossil Fuels. (1995). American Society for Testing and Materials, Philadelphia (USA), Vol. 5:1, Sect 5.

Atabani, A. E., Silitonga, A. S., Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., Badruddin, I. A., & Fayaz, H. (2013). Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. *Renewable and Sustainable Energy Reviews, 18*(2013), 211-245.

Azam, M. M., Waris, A., & Nahar, N. M. (2005). Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. *Biomass and Bioenergy, 29*(4), 293-302.

Aziz, M. A. A., Triwahyono, S., Jalil, A. A., Rapai, H. A. A., & Atabani, A. E. (2016). Transesterification of moringa oleifera oil to biodiesel over potassium fluoride loaded on eggshell catalyst. *Malaysian Journal of Catalysis, 1*(2016), 22-26.

Bello, E. I., & Makanju, A. (2011). Production, characterization and evaluation of castor oil biodiesel as alternative fuel for diesel engines. *Journal of Emerging Trends in Engineering and Applied Sciences, 2*(3), 525-530.

Berman, P., Nizri, S., & Wiesman, Z. (2011). Castor oil biodiesel and its blends as alternative fuel. *Biomass and Bioenergy, 35*(7), 2861-2866.

Bilal, S., Mohammed-Dabo, I. A., Nuhu, M., Kasim, S. A., Almustapha, I. H., & Yamusa, Y. A. (2013). Production of biolubricant from *Jatropha curcas* seed oil. *Journal of Chemical Engineering and Material Science, 4*(6), 72-79.

Birla, A., Singh, B., Upadhyay, S. N., & Sharma, Y. C. (2012). Kinetics studies of synthesis of biodiesel from waste frying oil using heterogeneous catalyst derived from snail shell. *Bioresource Technology, 106*(2012), 95-100.

Boey, P., Maniam, G., & Hamid, S. A. (2009a). Biodiesel from adsorbed waste oil on spent bleaching clay using CaO as a heterogeneous catalyst. *European Journal of Scientific Research, 33*(2), 347-357.

Boey, P. L., Maniam, G. P., & Hamid, S. A. (2009b). Biodiesel production via transesterification of palm olein using waste mud crab (*Scylla serrata*) shell as a heterogeneous catalyst. *Bioresource Technology, 100*(24), 6362-6368.

Boro, J., Thakur, A. J., & Deka, D. (2011). Solid oxide derived from waste shells of *Turbonilla striatula* as a renewable catalyst for biodiesel production. *Fuel Processing Technology, 92*(10), 2061-2067.

Borugadda, V. B., & Goud, V. V. (2015). Response surface methodology for optimization of bio lubricant basestock synthesis from high free fatty acids castor oil. *Energy Science Engineering, 3*(4), 371-383.

Bouaid, A., Boulifi, N. E., Martinez, M., & Aracil, J. (2012). Optimization of a two-step process for biodiesel production from Jatropha curcas crude oil. *International Journal of Low-Carbon Technologies, 7*(4), 331-337.

Buasri, A., Chaiyut, N., Loryuenyong, V., Wongweang, C., & Khamsrisuk, S. (2013a). Application of eggshell wastes as a heterogeneous catalyst for biodiesel production. *Sustainable Energy, 1*(2), 7-13.

Buasri, A., Chaiyut, N., Loryuenyong, V., Worawanitchaphong, P., & Trongyong, S. (2013b). Calcium oxide derived from waste shells of mussel, cockle, and scallop as the heterogeneous catalyst for biodiesel production. *The Scientific World Journal, 2013*, 1-7.

Buasri, A., Ksapabutr, B., Panapoy, M., & Chaiyut, N. (2012). Biodiesel production from waste cooking palm oil using calcium oxide supported on activated carbon as catalyst in a fixed bed reactor. *Korean Journal of Chemical Engineering, 29*(12), 1708-1712.

Chakrabarti, M. H., & Ahmad, R. (2008). Trans esterification studies on castor oil as a first step towards its use in bio diesel production. *Pakistan Journal of Botany, 40*(3), 1153-1157.

Chang, T. S., Masood, H., Yunus, R., Rashid, U., Choong, T. S. Y., & Biak, D. R. A. (2012). Activity of calcium oxide methoxide catalyst for synthesis of high oleic palm oil based trimethylolpropane triesters as lubricant base stock. *Industrial and Engineering Chemistry Research, 51*(15), 5438-5442.

Chauhan, P. S., & Chhibber, V. K. (2013a). Non-edible oil as a source of biolubricant for industrial applications : A review. *International Journal of Engineering Science and Innovative Technology, 2*(1), 299-305.

Chauhan, P. S., & Chhibber, V. K. (2013b). Non-edible oils as potential source for bio lubricant production and future prospects in India : A review. *Indian Journal of Applied Research, 3*(5), 1-4.

Chauhan, P. S., & Chhibber, V. K. (2013c). Chemical modification in karanja oil for biolubricant industrial application. *Journal of Drug Delivery & Therapeutics, 3*(3), 117-122.

Chermak, S. C., & Isbell, T. A. (2003). Synthesis and physical properties of estolide-based functional fluids. *Industrial Crops and Products, 18*, 183-196.

Dinda, S., Patwardhan, A. V., Goud, V. V., & Pradhan, N. C. (2008). Epoxidation of cottonseed oil by aqueous hydrogen peroxide catalysed by liquid inorganic acids. *Bioresource Technology*, *99*(2008), 3737-3744.

Drown, D. C., Harper, K., & Frame, E. (2001). Screening vegetable oil alcohol esters as fuel lubricity enhancers. *Journal of the American Oil Chemists' Society, 78*(6), 579-584.

Eevera, T., Rajendran, K., & Saradha, S. (2009). Biodiesel production process optimization and characterization to assess the suitability of the product for varied environmental conditions. *Renewable Energy, 34*(2009), 762-765.

El-Gendy, N. S., Hamdy, A., & Abu Amr, S. S. (2014). An investigation of biodiesel production from wastes of seafood restaurants. *International Journal of Biomaterials, 2014*(October), 1-17.

Encinar, J. M., Gonzalez, J. F., Martinez, G., Sanchez, N., & Gonzalez, C. G. (2010). Synthesis and characterization of biodiesel obtained from castor oil transesterification. *International Conference on Renewable Energies and Power Quality*.

Encinar, J. M., Gonzalez, J. F., & Rodriguez-Reinares, A. (2005). Biodiesel from used frying oil. Variables affecting the yields and characteristics of the biodiesel. *Industrial and Engineering Chemistry Research, 44*(2005), 5491-5499.

Erhan, S. Z., & Asadauskas, S. (2000). Lubricant basestocks from vegetable oils. *Industrial Crops and Products, 11*(2000), 277-282.

Erhan, S. Z., Sharma, B. K., & Perez, J. M. (2006). Oxidation and low temperature stability of vegetable oil-based lubricants. *Industrial Crops and Products, 24*(3), 292-299.

Ferdous, K., Deb, A., Ferdous, J., Uddin, R., Khan, M. R., & Islam, M. A. (2013). Preparation of biodiesel from higher FFA containing castor oil. *International Journal of Scientific & Engineering Research, 4*(12), 401-406.

Foglia, T. A., Nelson, L. A., Dunn, R. O., & Marmer, W. N. (1997). Low-temperature properties of alkyl esters of tallow and grease. *Journal of the American Oil Chemists' Society, 74*(8), 951-955.

Gawrilow, I. (2004). Vegetable oil usage in lubricants. *INFORM-International News on Fats, Oils and Related Materials, 15*(11), 702-705.

Gimbun, J., Ali, S., Kanwal, C. C. S. C., Shah, L. A., Hidayah, N., Ghazali, M., Cheng, C. K., & Nurdin, S. (2013). Biodiesel production from rubber seed oil using activated cement clinker as catalyst. *Procedia Engineering, 53*(2013), 13-19.

Goodrum, J. W., & Geller, D. P. (2005). Influence of fatty acid methyl esters from hydroxylated vegetable oils on diesel fuel lubricity. *Bioresource Technology, 96*(7), 851-855.

Granados, M. L., Poves, M. D. Z., Alonso, D. M., Mariscal, R., Galisteo, F. C., Moreno-Test, R., Santamaria, J., & Fierro, J. L. G. (2007). Biodiesel from sunflower oil by using activated calcium oxide. *Applied Catalysis B: Environmental, 73*(2007), 317-326.

Hu, S., Wang, Y., & Han, H. (2011). Utilization of waste freshwater mussel shell as an economic catalyst for biodiesel production. *Biomass and Bioenergy, 35*(2011), 3627-3635.

Ishak, A. A., & Salimon, J. (2012). Optimization process for esterification of rubber seed oil (RSO) with trimethylolpropane (TMP). *Journal of Science and Technology, 4,* 1-10.

Ishak, A. A., & Salimon, J. (2013). Synthesis of rubber seed oil and trimethylolpropane based biolubricant base stocks. *Malaysian Journal of Analytical Sciences, 17*(3), 414-421.

Ismail, M. (2015). Exploring the transesterification of castor oil to produce second generation biodiesel using a novel catalyst. *International Journal of Engineering Research & Technology, 4*(1), 289-293.

Ismail, S., Ahmed, A. S., Anr, R., & Hamdan, S. (2016). Biodiesel production from castor oil by using calcium oxide derived from mud clam shell. *Journal of Renewable Energy, 2016*(April), 1-8.

Istadi, I., Mabruro, U., Kalimantini, B. A., Buchori, L., & Anggoro, D. D. (2016). Reusability and stability tests of calcium oxide based catalyst (K_2O/CaO-ZnO) for transesterification of soybean oil to biodiesel. *Bulletin of Chemical Reaction Engineering and Catalysis, 11*(1), 34-39.

Istadi, I., Prasetyo, S. A., & Nugroho, T. S. (2015). Characterization of K_2O/CaO-ZnO catalyst for transesterification of soybean oil to biodiesel. *Procedia Environmental Sciences, 23*(2015), 394-399.

Jain, A. K., & Suhane, A. (2012). Research approach & prospects of non edible vegetable oil as a resource for biolubricant-A review. *Advanced Engineering and Applied Sciences: An International Journal, 1*(1), 23-32.

Jayadas, N. H., Nair, K. P., & Ajithkumar, G. (2007). Tribological evaluation of coconut oil as an environment-friendly lubricant. *Tribology International, 40*(2007), 350-354.

Jiang, S. T., Zhang, F. J., & Pan, L. J. (2010). Sodium phosphate as a solid catalyst for biodiesel preparation. *Brazilian Journal of Chemical Engineering, 27*(1), 137-144.

Kaur, M., & Ali, A. (2011). Lithium ion impregnated calcium oxide as nano catalyst for

the biodiesel production from karanja and jatropha oils. *Renewable Energy, 36*(2011), 2866-2871.

Knothe, G., & Steidley, K. R. (2005). Kinematic viscosity of biodiesel fuel components and related compounds. Influence of compound structure and comparison to petrodiesel fuel components. *Fuel, 84*(2005), 1059-1065.

Knothe, G. (2010). Biodiesel and renewable diesel: A comparison. *Progress in Energy and Combustion Science, 36*(2010), 364-373.

Kouzu, M., & Hidaka, J. (2012). Transesterification of vegetable oil into biodiesel catalyzed by CaO : A review. *Fuel, 93*(2012), 1-12.

Kumar, D., & Ali, A. (2014). Potassium ion impregnated calcium oxide as a nanocrystalline solid catalyst for biodiesel production from waste cotton seed oil. *Energy Sources Part a-Recovery Utilization and Environmental Effects, 36*(10), 1093-1102.

Kumar, D., & Ali, A. (2012). Nanocrystalline K-CaO for the transesterification of a variety of feedstocks: Structure, kinetics and catalytic properties. *Biomass and Bioenergy, 46*(2012), 459-468.

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

Li, Y., Jiang, Y., & Gao, J. (2015). Heterogeneous catalyst derived from waste shells for biodiesel production. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 37*(6), 598-605.

Ma, F., Clements, L. D., & Hanna, M. A. (1998). The effects of catalyst, free fatty acids and water on transesterification of beef tallow. *Transactions of the ASAE, 41*(5), 1261-1264.

Mahmud, H. A., Salih, N., & Salimon, J. (2015). Oleic acid based polyesters of trimethylolpropane and pentaerythritol for biolubricant application. *Malaysian Journal of Analytical Sciences, 19*(1), 97-105.

Madankar, C. S., Pradhan, S., & Naik, S. N. (2012). Production of bio lubricants from castor oil in sub and supercritical carbon dioxide mediated enzymatic reactions. *10th International Symposium on Supercritical Fluids (ISSF2012),* 1-5.

Margaretha, Y. Y., Prastyo, H. S., Ayucitra, A., & Ismadji, S. (2012). Calcium oxide from *Pomacea sp.* Shell as a catalyst for biodiesel production. *International Journal of Energy and Environmental Engineering, 3*(33), 1-9.

Menkiti, M., Anaehobi, H., Oyoh, K., & Nnaji, P. (2015). Process optimization and kinetics of biolubricant synthesis from fluted pumpkin seed. *European Scientific Journal, 11*(27), 30-47.

Mirghiasi, Z., Bakhtiari, F., Darezereshki, E., & Esmaeilzadeh, E. (2014). Preparation and characterization of CaO nanoparticles from $Ca(OH)_2$ by direct thermal decomposition method. *Journal of Industrial and Engineering Chemistry, 20*(2014), 113-117.

Mobarak, H. M., Niza Mohamad, E., Masjuki, H. H.,Kalam, M. A., Al Mahmud, K. A. H., Habibullah, M., & Ashraful, A. M. (2014). The prospects of biolubricants as alternatives in automotive applications. *Renewable and Sustainable Energy Reviews, 33*(2014), 34-43.

Moradi, G. R., Mohadesi, M., Ghanbari, M., Moradi, M. J., Hosseini, Sh., & Davoodbeygi, Y. (2015). Kinetic comparison of two basic heterogeneous catalysts obtained from sustainable resources for transesterification of waste cooking oil. *Biofuel Research Journal, 6*(2015), 236-241.

Musa, U., Mohammed, I. A., Sadiq, M. M., Aberuagba, F., Olurinde, A. O., & Obamina, R. (2016). Synthesis and characterization of trimethylolpropane-based biolubricant from castor oil. *Proceedings of the 45th Annual Conference of NSChE,* 248-253.

Nie, J. (2012). Synthesis and evaluation of polyol based biolubricants from vegetable oils. *Department of Food and Bioproduct Sciences*, Master (September).

Niju, S., Begum, K. M. M. S., & Anantharaman, N. (2014). Modification of egg shell and its application in biodiesel production. *Journal of Saudi Chemical Society, 18*(2014), 702-706.

Nurdin, S., Misebah, F. A., Haron, S. F., Ghazali, N. S., Yunus, R. M., & Gimbun, J. (2014a). Activated *Paphia undulate* shells waste (APSW): A cost-effective catalyst for biodiesel synthesis from rubber and *Jatropha curcas* seeds oil (RSOME & JSOME). *International Journal of Chemical Engineering and Applications, 5*(6), 483-488.

Nurdin, S., Misebah, F. A., Yunus, R. M., Mahmud, M. S., & Sulaiman, A. Z. (2014b). Conversion of *Jatropha curcas* oil to ester biolubricant using solid catalyst derived from saltwater clam shell waste (SCSW). *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, 8*(9), 999-1005.

Nurdin, S., Rosnan, N. A., Ghazali, N. S., Gimbun, J., Nour, A. H., & Haron, S. F. (2015a). Economical biodiesel fuel synthesis from castor oil using mussel shell-base catalyst (MS-BC). *Energy Procedia, 79*(2015), 576-583.

Nurdin, S., Fatimah, A. M., Haron, S. F., &Yunus, R. M. (2015b). Transesterification kinetics of jatropha methyl ester and trimethylolpropane for biolubricant synthesisi using *Paphiaundulata* shell waste. *Advances in Environmental Biology, 9*(1), 35-43.

Nurfitri, I., Maniam, G. P., Hindryawati, N., Yusoff, M. M., & Ganesan, S. (2013). Potential of feedstock and catalysts from waste in biodiesel preparation: A review. *Energy Conversion and Management, 74*(2013), 395-402.

Ogunniyi, D. S. (2006). Castor oil : A vital industrial raw material. *Biresource Technology, 97*(9), 1086-1091.

Omari, A., Mgani, Q. A., & Mubofu, E. B. (2015). Fatty acid profile and physico-chemical parameters of castor oils in Tanzania. *Green and Sustainable Chemistry, 5*(November), 154-163.

Pavia, D. L., Lampman, G. M., & Kriz, G. S. (2010). Introduction to spectroscopy. 4th

edition., United States: Thomson Learning, Inc.

Predojevic, Z. J. (2008). The production of biodiesel from waste frying oils: A comparison of different purification steps. *Fuel, 87*(2008), 3522-3528.

Rashid, U., Anwar, F., Moser, B. R., & Knothe, G. (2008). *Moringa oleifera* oil: A possible source of biodiesel. *Bioresource Technology, 99*(2008), 8175-8179.

Resul, M. F. M. G., Ghazi, T. I. M., & Idris, A. (2011). Temperature dependence on the synthesis of jatropha biolubricant. *IOP Conference Series: Materials Science and Engineering, 17* (2011), 1-11.

Resul, M. F. M. G., Ghazi, T. I. M., & Idris, A. (2012). Kinetic study of jatropha biolubricant from transesterification of jatropha curcas oil with trimethylolpropane: Effects of temperature. *Industrial Crops and Products, 38*(2012), 87-92.

Resul, M. F. M. G., Ghazi, T. I. M., Syam, A. M., & Idris, A. (2008). Synthesis of biodegradable lubricant from jatropha oil with high content of free fatty acids. *American Institute of Chemical Engineers (AICHE) Annual Meeting*, 1-7.

Rezaei, R., Mohadesi, M., & Moradi, G. R. (2013). Optimization of biodiesel production using waste mussel shell catalyst. *Fuel, 109*(2013), 534-541.

Rohim, R., Ahmad, R., Ibrahim, N., Hamidin, N., & Abidin, C. Z. A. (2014). Characterization of calcium oxide catalyst from eggshell waste. *Advances in Environmental Biology, 8*(22), 35-38.

Salimon, J., Noor, D. A. M., Nazrizawati, A. T., Firdaus, M. Y. M., & Noraishah, A. (2010). Fatty acid composition and physicochemical properties of Malaysian castor bean *Ricinus communis* L. seed oil. *Sains Malaysiana, 39*(5), 761-764.

Salimon, J., & Salih, N. (2010). Chemical modification of oleic acid oil for biolubricant industrial applications. *Australian Journal of Basic and Applied Sciences, 4*(7), 1999-2003.

Salimon, J., Salih, N., & Yousif, E. (2010). Biolubricants: Raw materials, chemical modifications and environmental benefits. *European Journal of Lipid Science and Technology, 112*(5), 519-530.

Salimon, J., Salih, N., & Yousif, E. (2012). Biolubricant basestocks from chemically modified ricinoleic acid. *Journal of King Saud University-Science, 24*(2014), 11-17.

Samart, C., Sreetongkittikul, P., & Sookman, C. (2009). Heterogeneous catalysis of transesterification of soybean oil using KI/mesoporous silica. *Fuel Processing Technology, 90*(2009), 922-925.

Sanjay, B. (2013). Heterogeneous catalyst derived from natural resources for biodiesel production: A review. *Research Journal of Chemical Sciences, 3*(6), 95-101.

Santos Politi, J. R. d., Matos, P. R. R. d., & Sales, M. J. A. (2013). Comparative study of the oxidative and thermal stability of vegetable oils to be used as lubricant bases. *Journal of Thermal Analysis and Calorimetry, 111*(2), 1437-1442.

Scholz, V., & Silva, J. N. d. (2008). Prospects and risks of the use of castor oil as a fuel. *Biomass and Bioenergy, 32*(2), 95-100.

Schuster, H., Rios, L. A., Weckes, P. P., & Hoelderich, W. F. (2008). Heterogeneous catalysts for the production of new lubricants with unique properties. *Applied Catalysis A: General, 348*(2008), 266-270.

Shah, G. C., Yadav, M., & Tiwari, A. (2013). Evaluation of different algal species for the higher production of biodiesel. *Journal of Petroleum Technology and Alternative Fuels, 4*(1), 1-6.

Sharma, Y. C., Singh, B., & Korstad, J. (2010). Application of an efficient nonconventional heterogeneous catalyst for biodiesel synthesis from *Pongamia pinnata* oil. *Energy and Fuels, 24*(5), 3223-3231.

Shrivastava, A., Sandagar, P., Baja, I., & Singhal, R. (2008). Media optimization for the production of U-linolenic acid by cunninghamella echinulata varielegans MTCC 522 using response surface methodology. *International Journal Food Engineering, 4*(2), 1-32.

Silva, J. P. V. d., Serra, T. M., Gossmann, M., Wolf, C. R., Meneghetti, M. R., & Meneghetti, S. M. P. (2010). *Moringa oleifera* oil: Studies of characterization and biodiesel production. *Biomass and Bioenergy, 34*(10), 1527-1530.

Silva Cesar, A. d., & Batalha, M. O. (2010). Biodiesel production from castor oil in Brazil: A difficult reality. *Energy Policy, 38*(2010), 4031-4039.

Silva, J. A. C. d. (2011). Biodegradable lubricants and their production via chemical catalysis. *Tribology-Lubricants and Lubrication.*

Srivastava, A., & Sahai, P. (2013). Vegetable oils as lube basestocks: A review. *African Journal of Biotechnology, 12*(9), 880-891.

Sulaiman, S. Z., Chuah, A. L., & Fakhru'l-Razi, A. (2007). Batch production of trimethylolpropane ester from palm oil as lubricant base stock. *Journal of Applied Sciences, 7*(15), 2002-2005.

Viriya-empikul, N., Krasae, P., Nualpaeng, W., Yoosuk, B., & Faungnawakij, K. (2012). Biodiesel production over Ca-based solid catalysts derived from industrial wastes. *Fuel, 92*(1), 239-244.

Viriya-empikul, N., Krasae, P., Puttasawat, B., Yoosuk, B., Chollacoop, N., & Faungnawakij, K. (2010). Waste shells of mollusk and egg as biodiesel production catalysts. *Biresource Technology, 101*(10), 3765-3767.

Wagner, H., Luther, R., & Mang, T. (2001). Lubricant base fluids based on renewable raw materials: Their catalytic manufacture and modification. *Applied Catalysis A: General, 221*(2001), 429-442.

Wang, E., Ma, X., Tang, S., Yan, R., Wang, Y., Riley, W. W., & Reaney, M. J. T. (2014). Synthesis and oxidative stability of trimethylolpropane fatty acid triester as a biolubricant base oil from waste cooking oil. *Biomass and Bioenergy, 66*(2014), 371-378.

Warra, A. A. (2015). Physico-chemical and GC/MS analysis of castor bean (*Ricinus communis* L.) seed oil. *Chemistry and Materials Research, 7*(2), 56-60.

Wei, Z., Xu, C., & Li, B. (2009). Application of waste eggshell as low-cost solid catalyst for biodiesel production. *Biresource Technology, 100*(10), 2883-2885.

Wen, L., Wang, Y., Lu, D., Hu, S., & Han, H. (2010). Preparation of KF/CaO nanocatalyst and its application in biodiesel production from Chinese tallow seed oil. *Fuel, 89*(9), 2267-2271.

Willing, A. (2001). Lubricants based on renewable resources- an environmentally compatible alternative to mineral oil products. *Chemosphere, 43*(2001), 89-98.

Witoon, T. (2011). Characterization of calcium oxide derived from waste eggshell and its application as CO_2 sorbent. *Ceramics International, 37*(8), 3291-3298.

Wu, W. H., Foglia, T. A., Marmer, W. N., Dunn, R. O., Goering, C. E., & Briggs, T. E. (1998). Low-temperature property and engine performance evaluation of ethyl and isopropyl esters of tallow and grease. *Journal of the American Oil Chemists' Society, 75*(9), 1173-1178.

Wu, X., Zhang, X., Yang, S., Chen, H., & Wang, D. (2000). The study of epoxidized rapeseed oil sed as a potential biodegradable lubricant. *Journal of the American Oil Chemists, 77*(5), 561-563.

Xie, W., & Huang, X. (2006). Synthesis of biodiesel from soybean oil using heterogeneous KF/ZnO catalyst. *Catalysis Letters, 107*(1-2), 53-59.

Yao, L., Hammond, E. G., Wang, T., Bhuyan, S., & Sundararajan, S. (2010). Synthesis and physical properties of potential biolubricants based on ricinoleic acid. *JAOCS, Journal of the American Oil Chemists' Society, 87*(8), 937-945.

Yunus, R., Fakhru'l-razi, A., Ooi, T. L., Iyuke, S. E., & Idris, A. (2003). Development of optimum synthesis method for transesterification of palm oil methyl esters and trimethylolpropane to environmentaly acceptable palm oil-based lubricant. *Journal of Oil Palm Research, 15*(2), 35-41.

Yunus, R., Fakhru'l-Razi, A., Ooi, T. L., Iyuke, S. E., & Idris, A. (2003). Preparation and characterization of trimethylolpropane esters from palm kernel oil methyl esters. *Journal of Oil Palm Research, 15*(2), 42-49.

Yunus, R., Fakhru'l-Razi., Ooi, T. K., Biak, D. R. A., & Iyuke, S. E. (2004). Kinetics of transesterification of palm-based methyl esters with trimethylolpropane. *Journal of the American Oil Chemists' Society, 81*(5), 497-503.

Zhang, Y., Shen, X., Bai, H., & Liu, S. (2012). Calcination of waste mussel shell used as catalyst in producing biodiesel. *World Automation Congress (WAC).*

Zhang, Y., Liu, S., & Chen, P. (2013). Study on the properties of calcined waste mussel shell. *Nature Environment and Pollution Technology, 12*(3), 435-438.