

PHYSICOCHEMICAL PROPERTIES OF BIODIESEL PRODUCT DERIVED FROM LARD OIL USING EGGSHELLS AS A GREEN CATALYST

Wuttichai Roschat^{1,2*}, Sunti Phewphong¹, Preecha Moonsin³,
Phongsakorn Pholsupho² and Supitcha Yapan²

Received: December 16, 2018; Revised: February 14, 2019; Accepted: February 20, 2019

Abstract

Eggshells-derived CaO was used as a catalyst for biodiesel production from lard oil via transesterification reaction. The eggshell materials were calcined in air with the hydrothermal synthesis route at 800°C for 3 h. Conversion of lard oil to biodiesel product (fatty acid ethyl ester; FAME) was higher than 97% by using methanol to oil molar ratio of 15:1, catalyst loading amount of 5 wt.%, reaction temperature of 65°C and reaction time for 3 h. Physicochemical properties of biodiesel product prepared from lard oil were evaluated according to the main property for bio-auto fuels both the ASTM and EN standards namely kinematic viscosity at 40°C, oxidation stability, methyl ester content, acid number, pour point, cloud point and thermal stability decomposition. All of the physicochemical properties of lard oil biodiesel were compared with palm oil biodiesel, rubber seed oil biodiesel and petroleum diesel. The results in this research showed that lard oil derived biodiesel product has high quality property than palm oil biodiesel and rubber seed oil biodiesel. Therefore, lard oil is one of the attractive candidate feedstock for biodiesel production in Thailand because of inexpensiveness, high potentiality and produced high grade biodiesel product.

Keywords: biodiesel, lard oil, physicochemical properties, eggshells, CaO

¹ Biomass Energy Research Laboratory, Center of Excellence on Alternative Energy, Research and Development Institution, Sakon Nakhon Rajabhat University, Sakon Nakhon, 47000, Thailand.

² Program of Chemistry, Faculty of Science and Technology, Sakon Nakhon Rajabhat University, Sakon Nakhon, 47000, Thailand. E-mail: roschat1@gmail.com

³ Program of Chemistry, Faculty of Science, Ubon Ratchathani Rajabhat University, Ubon Ratchathani, 34000, Thailand.

* Corresponding author

Introduction

Fatty acid methyl ester (FAME) or biodiesel is one of the most candidates attractive as an alternative renewable energy for conventional diesel fuel. The advantages of biodiesel over petroleum diesel oil are lower CO₂, CO, SO_x and NO_x gases emission, non-toxic, lower particulate matter and smoke, clean and biodegradability, environmental friendly and inexpensive (Winayanuwattikun *et al.*, 2008; Jose *et al.*, 2014; Arshad *et al.*, 2018; Huppa *et al.*, 2018). In addition, biodiesel is also produced from several sources of vegetable oil such as palm oil, soybean oil, rice bran oil, coconut oil and jatropha oil which some of them are raw food materials (Winayanuwattikun *et al.*, 2008; Huang *et al.*, 2012; Giakoumis *et al.*, 2018). The other important raw material source for biodiesel production is waste cooking oil which is one of the interesting choices for substitution edible oil. Nevertheless, the qualities of waste cooking oil also lead to inconvenience and difficulty in the process of biodiesel production. For example free fatty acid (FFA) and water content in the oil bring to soap formation in the reaction mixture which is the significant problems in the production process (Che *et al.*, 2012; Sahar *et al.*, 2018).

Animal fats are attractive as an alternative raw material for biodiesel product due to they can be produced from agricultural livestock. Lard oil is one of a kind of animal fats that high potential feedstock for biodiesel production because they are a short chain hydrocarbon compound, low FFA and high oxidative stability than vegetable oils (Hong *et al.*, 2015; Ezekannagha *et al.*, 2017). In Thailand, there are many pigs for consumption in the country and for exports approximately 10,200,000 pigs in 2017 (Department of Livestock Development, Ministry of Agriculture and Cooperatives, 2017). Additionally, it is well known that the consumption lard oil lead to increase LDL (Low Density Lipoprotein) which increasing the risk of developing heart disease and strokes due to lard oil have high saturated fatty acid content (~35-40%) (Rohman *et al.*, 2012, Hong *et al.*, 2015; Ezekannagha *et al.*, 2017)

when compared with rice bran oil (saturated fatty acid content ~23%), soybean oil (saturated fatty acid content ~14%) and sunflower oil (saturated fatty acid content ~10.4%) (Winayanuwattikun *et al.*, 2008). In this point, the utilization of lard oil as a raw material for biodiesel production is choice to promote renewable energy from biomass source.

In most of the research work reported biodiesel production via transesterification reaction using CaO as a heterogeneous catalyst because it shows good catalytic activity in mild reaction conditions, less solubility in methanol, non-toxicity, environmental friendly and it can be generated from natural calcium carbonate material such as eggshells, waste shells (e.g. ostrich eggshells, meretrix venus shells, golden apple snail shells and mollusk shells) and limestone (Viriya-empikul *et al.*, 2012; Chen *et al.*, 2014; Roschat *et al.*, 2016). Therefore, this work focus on the utilization of lard oil as starting material to produce biodiesel product and using CaO derived from eggshells as a catalyst. Thin layer chromatography (TLC) was applied to monitor the reaction progress of the conversion of lard oil to biodiesel product. The synthesized biodiesel was analyzed by using nuclear magnetic resonance (NMR) technique and thermo gravimetric analysis (TGA) technique. The important properties for bio-auto fuels of the obtained lard oil biodiesel namely kinematic viscosity, methyl ester content, oxidation stability, acid number, pour point, cloud point, and ash content were evaluated according to EN 14214 and ASTM standard method and compared with palm oil biodiesel, rubber seed oil biodiesel and petroleum diesel.

Materials and Methods

Materials

Lard oil (FFA amount of 1.04%) as starting material for synthesized biodiesel was purchased from local Thai market and used without any purification. Raw eggshells were obtained from local restaurants and canteen.

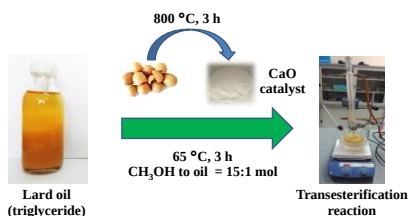


Figure 1. The diagram of the biodiesel production process via transesterification reaction of lard oil catalyzed by CaO obtained from calcined eggshells

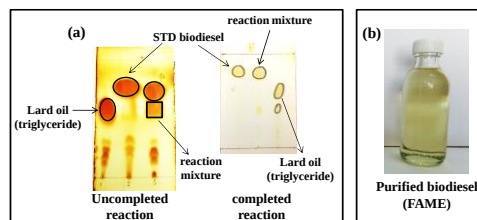


Figure 2. (a) TLC plate of following the progress transesterification reaction of lard oil to biodiesel product and (b) purified lard oil biodiesel product in this work

Methyl alcohol analytical reagent grade, hexane commercial grade, petroleum ether analytical reagent grade, diethyl ether analytical reagent grade, glacial acetic acid, potassium hydroxide (KOH) 99.0% and sodium hydroxide (NaOH) 99.0% purity were purchased from Fluka and Acros Chemical Co. Ltd. Hammett indicators including phenolphthalein ($pK_a = 9.3$), thymolphthalein ($pK_a = 9.9$), indigo carmine ($pK_a = 12.2$), 2,4-dinitroaniline ($pK_a = 15.0$), and 4-nitroaniline ($pK_a = 18.4$) were purchased from Aldrich and Fluka. Palm olein oil was purchased from Morakot Industries PCL., Thailand. TLC plate (Silica Gel 60 F₂₅₄) was obtained from Merck, Darmstadt, Germany.

Catalyst Preparation and Characterization

The raw eggshells were washed with water, dried in an oven, mashed into powder using a ball mill, sieved and calcined in a furnace at 800°C for 3 h following the method of Viriya-empikul *et al.* (2012), Roschat *et al.* (2017 and 2018). The obtained CaO catalyst was kept in a glass bottle container without moisture and air. The CaO catalyst was characterized by X-ray diffraction (XRD) method with XRD-6100 Shimadzu, Japan followed the condition of Cu K α radiation ($\lambda = 1.5418 \text{ \AA}$) at 1,600 W, 40 kV and 40 mA, and 0.02° per step. Hammett indicator method was applied to determine the basic strength of the CaO catalyst.

Transesterification Reaction

The transesterification reactions of lard oil and palm oil to biodiesel product were

performed in a three-neck round bottom flask batch reactor as depicted in Figure 1. The reaction condition consist of methanol to oil molar ratio of 15:1, catalyst loading amount of 5 wt%, reaction temperature of 65°C and reaction time for 3 h which was optimal condition following the report of Roschat *et al.* (2018). As displayed in Figure 2(a), TLC technique was used to monitor the conversion progress of lard oil to biodiesel product with the mixture developing solvent between petroleum ether, diethyl ether and glacial acetic acid as the ratio of 85:15:1 v/v/v. After that, the dried TLC plate was stained with iodine vapor to identify the liquid spot of the sample (Supamathanon *et al.*, 2011).

After completion of the reaction, the reaction mixture (biodiesel, glycerol, methanol and CaO catalyst) was filtered to separate the catalyst. The liquid mixture was transferred to separatory funnel for separating glycerol to obtain biodiesel product. The biodiesel product was heated at 80°C to eliminate the excess methanol and then it was purified by hexane extraction, respectively. The final biodiesel product after purification as shown in Figure 2(b) was evaluated the important properties following ASTM and EN 14214 standard method for biodiesel fuels.

Results and Discussion

Characterization of CaO Catalyst Derived from Eggshells

In this part, the XRD pattern of the calcined eggshells catalyst as displayed in

Figure 3, found the peaks at 2θ of 32° , 37° , 53° , 64° , and 67° matching with XRD pattern of CaO crystalline material according to the reference number as PDF No. 00-048-1467. In addition, the basic strengths of CaO obtained from calcination eggshells tested by Hammett indicator method showed H_- values in the range of 15.0–18.4 due to it could change the coloration of 2,4-dinitroaniline ($pK_a = 15$) but could not with 4-nitroaniline ($pK_a = 18.4$). On the other hand, eggshells powder showed basic strength values lower than 9.3 because they gave colorless with phenolphthalein ($pK_a = 9.3$). Hence, all of the evidences of this study indicated that calcination eggshells at 800°C for 3 h completely converted calcium carbonate phase into calcium oxide phase according with the reports of Viriya-empikul *et al.* (2012), Chavan *et al.* (2015), Roschat *et al.* (2017) and Roschat *et al.* (2018).

Transesterification Reaction of Lard Oil to Lard Oil Biodiesel

Biodiesel production of lard oil to lard oil biodiesel in the present work was presented via transesterification reaction by using the conditions of methanol to oil molar ratio of 15:1, catalyst loading amount of 5 wt.%, reaction temperature of 65°C and reaction time for 3 h referred the method from the report of Roschat *et al.* (2018). The obtained biodiesel product was simply tested by TLC technique (Figure 2(a)) for determination the progress of the reaction, while the conversion of lard oil to methyl ester (biodiesel) was evaluated by $^1\text{H-NMR}$ technique as depicted in Figure 4.

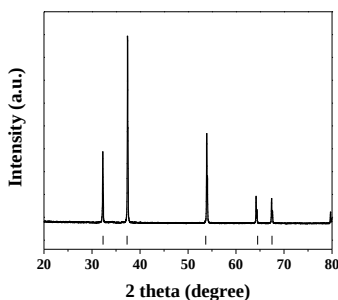


Figure 3. X-ray diffractograms of eggshells calcined at 800°C for 3 h

Figure 4(a) illustrated lard oil as triglyceride structure which could be observed from glyceridic protons ($-\text{OCO}-\text{CH}_2-\text{CH}(\text{OCO})-\text{CH}_2-\text{OCO}-$) assigned at 4.16, 4.31 and 5.29 ppm, respectively. While lard oil transformed to methyl ester completely, $^1\text{H-NMR}$ spectra would be only appearing the peak methyl ester proton ($\text{CH}_3-\text{OCO}-\text{R}$) at chemical shifts 3.69 ppm (Figure 4(b)) and absent of the glyceridic protons (4.16, 4.31 and 5.29 ppm). These results were accorded with the reports of Roschat *et al.* (2017 and 2018), Yadav *et al.* (2017) and Shimamoto *et al.* (2017), who applied the $^1\text{H-NMR}$ technique to analyze and characterize biodiesel product.

Furthermore, the thermogravimetric analysis was used to confirm the purity of the obtained biodiesel product as displayed in Figure 5. The weight loss of lard oil started at around 375°C and completely degraded at 475°C with mass loss over 99.5%. Identically, the mass loss

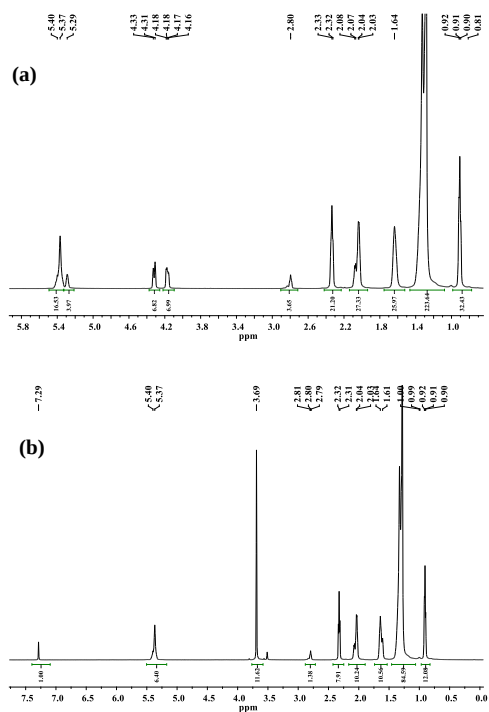


Figure 4. $^1\text{H-NMR}$ spectrum of (a) lard oil as raw material and (b) the synthesized biodiesel from lard oil catalyzed by eggshells-derived CaO catalyst

of lard oil biodiesel began approximately at 200°C and the end of decomposition temperature at 350°C with more than 98.0% of weight degradation. TGA data confirmed that the conversion of lard oil to biodiesel product catalyzed by CaO obtained from eggshells was completely and the obtained biodiesel product was clean bio-auto fuel because it was completely decomposed at the lower temperature in a cylinder of engine in the process of compress air without fuel with temperature of ~700-800°C (Sivakumar *et al.*, 2011; Vega-Lizama *et al.*, 2015; Roschat *et al.*, 2017).

According to the GC analysis standard method (EN 14214) of all the obtained biodiesel product derived from lard oil, palm oil, and rubber seed oil showed that all of the biodiesel products meet within fuel properties

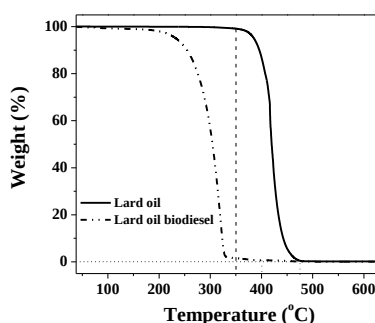


Figure 5. Thermogravimetric curve of the final biodiesel production derived from lard oil and using CaO from eggshells as a green heterogeneous catalyst

of specifications in the biodiesel standards with FAME value over 96.5% (Knothe and Razon, 2017, Roschat *et al.*, 2017 and 2018, Giakoumis and Sarakatsanis, 2018). Additionally, the fatty acid methyl ester composition of lard oil biodiesel, palm oil biodiesel and rubber seed oil biodiesel were presented in Table 1. Lard oil biodiesel in this work consists of total saturated fatty acids methyl esters of 42.5 wt% mainly palmitic acid methyl ester (C16:0) and stearic acid methyl ester (C18:0), while total unsaturated fatty acid methyl esters around 57.5 wt% were oleic acid methyl ester (C18:1) and linoleic acid methyl ester (C18:2), respectively. Similar results has also been found by palm oil biodiesel composting saturated fatty acid methyl ester approximately 42 wt% mainly palmitoleic acid methyl ester (C16:1) and 57.8 wt.% unsaturation comprising namely oleic acid methyl ester (C18:1) and Linoleic acid methyl ester (C18:2). On the other hand, rubber seed oil biodiesel consists of only 15.7 wt% saturation fatty acid methyl ester, it showed high unsaturation fatty acid methyl ester more than 84 wt% which be similar to the reports both Ramadhas *et al.* (2005) and Roschat *et al.* (2017).

High saturated fatty acid methyl ester has directly affected to the increasing of cloud point and pour point, nevertheless, oxidation stability of biodiesel was also improved. Whereas highly polyunsaturated of fatty acid methyl ester would be reduced cloud point and pour point, the oxidation stability property was decreased. Therefore, the balance of saturated

Table 1. The fatty acid methyl ester (FAME) composition of lard oil biodiesel, palm oil biodiesel and rubber seed oil biodiesel

FAME	Composition (wt%)		
	lard oil biodiesel	palm oil biodiesel	rubber seed oil biodiesel
Lauric acid methyl ester (C12:0)	0.5	0.3	-
Myristic acid methyl ester (C14:0)	2.0	0.7	-
Palmitic acid methyl ester (C16:0)	24.6	37.3	9.5
Palmitoleic acid methyl ester (C16:1)	2.8	0.3	0.2
Stearic acid methyl ester (C18:0)	14.8	3.7	6.0
Oleic acid methyl ester (C18:1)	42.8	46.0	24.5
Linoleic acid methyl ester (C18:2)	11.1	11.1	44.6
Linolenic acid methyl ester (C18:3)	0.8	0.4	15.0
Arachidic acid methyl ester (C20:0)	0.6	0.2	0.2
Total saturated fatty acids methyl esters	42.5	42.2	15.7
Total unsaturated fatty acid methyl esters	57.5	57.8	84.3

and unsaturated fatty acid methyl ester promising approached to improve biodiesle properties into high quality bio-auto liquid fuel. This result suggested that chemical structure of lard oil biodiesle was suitable identically with palm oil biodiesle and better than rubber seed oil biodiesle in term of providing the higher oxidation stability and tolerant on lower temperature (lower cloud point and pour point).

Moreover, the heating value as well as heat of combustion of the obtained biodiesle product was higher than rubber seed oil biodiesle and closer with palm oil biodiesle but lower than petroleum diesel oil as demonstrated in Figure 6. This result indicated

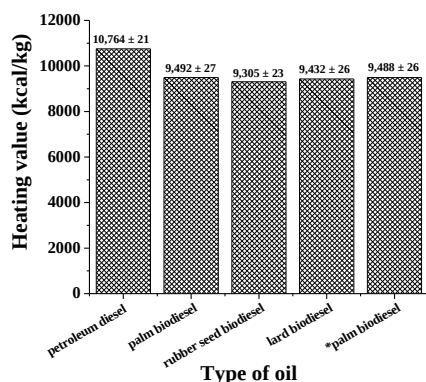


Figure 6. Heating values of the final biodiesle production derived from lard oil and using CaO from eggshells as a green heterogeneous catalyst

the involving efficacy of liquid fuel compared between biodiesle oil against petroleum diesel oil when applied in automotive. Though petroleum diesel oil could be gave higher engine power than biodiesle oil, biodiesle oil was low-cost than petroleum diesel oil. In terms of value as an alternative energy source with inexpensiveness, green and global friendly of lard oil biodiesle, they should be promoted for applications substituted or blended together with petroleum diesel oil.

The Study of Lard Oil Biodiesle Properties

The important bio-auto fuels properties of lard oil biodiesle were evaluated using both ASTM D6751 and EN 14214 standard method which performed by biodiesle testing unit, the National Science and Technology Development Agency, Thailand as summarized results in Table 2 and referred to the method following the reports of Niju *et al.*, 2014, Chavan *et al.*, 2015, Knothe and Razon, 2017, Roschat *et al.*, 2017 and 2018, Giakoumis and Sarakatsanis, 2018.

The lard oil, palm oil and rubber seed oil have high kinematic viscosity of 25.52, 28.94 and 27.31 cSt, respectively. After the transferring was completely of the triglyceride to biodiesle product, the kinematic viscosity of lard oil biodiesle, palm oil biodiesle and rubber seed oil biodiesle was decreased as 3.89, 4.45, and 4.87 cSt, respectively. Furthermore, ash content, pour point and cloud point of lard oil biodiesle has also lower than both palm oil biodiesle and rubber seed oil biodiesle signified the high

Table 2. The fuel properties of the lard oil biodiesle comparison with petroleum diesel oil, palm oil biodiesle and rubber seed oil biodiesle

Parameters	Standard biodiesle	petroleum diesel oil	palm oil biodiesle	rubber seed oil biodiesle	lard oil biodiesle
Kinematic viscosity at 40 °C (cSt) ^a	3.5-5.0	2.85±0.01	4.45±0.01	4.87±0.02	3.89±0.04
Oxidation stability (h) ^b	≥6	>20	13.53	8.12	14.52
Methyl ester content (%) by GC ^c	96.5	-	96.8	97.7	97.5
Methyl ester content (%) by NMR ^d	-	-	98.0	97.0	97.2
Acid number (mg KOH/g oil) ^e	<0.5	<0.05	0.25	0.45	0.37
Pour point (°C) ^f	-15 to +16	<-15	+6	+6	+5
Cloud point (°C) ^g	-3 to +12	<-5	+8	+10	+8
Ash content (%w/w oil) ^h	≤0.01	0.0020	0.0067	0.0343	0.0021

Specifications in the biodiesle standards; ^a EN 14214 (method EN ISO 3104), ^b EN 14214 (method EN 12412), ^c EN 14214 (method 14103:2011), ^d non-standard (ref. Roschat *et al.*, 2018, Shimamoto *et al.*, 2017), ^e ASTM D6751 (method D664), ^f ASTM D6751 (method ISO 3016), ^g ASTM D6751 (method EN 116), ^h ASTM D975 (method D482).

quality properties of lard biodiesel due to these parameters were directly affected to perform the injection and ignition in combustion chamber of engine. In addition, all of the results found that lard oil biodiesel showed high quality properties within the acceptable standard biodiesel product all of the main parameters that tested in this work and according to the ASTM and EN standard methods for bio-auto fuel. Therefore, the obtained biodiesel product from lard oil was not only the renewable energy but also environmentally-friendly and clean fuel energy.

Conclusions

The present study involved that the biodiesel production of lard oil to biodiesel product by using CaO material prepared from calcined eggshells as green heterogeneous catalyst. All the results demonstrated that the calcined eggshells have high activity to convert lard oil to be high quality biodiesel product under the mild reaction conditions. The %FAME yield of the synthesized biodiesel product was more than 97% and all the parameters for the obtained lard oil biodiesel like the kinematic viscosity, oxidation stability, acid number, pour point, cloud point and ash content were evaluated and found to meet with the standards method for liquid bio-auto fuels both EN 14214 and ASTM D6751. Hence, using lard oil as a feedstock and CaO catalyst generated from eggshells for biodiesel production not only could improve the cost-efficient but also obtained the high quality biodiesel product which was green, economically and high potential for application to scaling up for the industrial production.

Acknowledgments

The authors were extremely thankful to the scholarship support from funded research projects and creative work of Faculty of Science and Technology, Sakon Nakhon Rajabhat University-Thailand, in the fiscal year 2019. The authors were also extremely

grateful to Program of Chemistry, Faculty of Science and Technology, Biomass Energy Research Laboratory under Center of Excellence on Alternative Energy, Sakon Nakhon Rajabhat University-Thailand, for providing the equipment and tools for experimentation. In addition, we were thankful to Vidyasirimedhi Institute of Science and Technology-Thailand, for testing the obtained biodiesel with ^1H -NMR spectroscopy and National Metal and Materials Technology Center (MTEC)-Thailand, for testing fuel properties of the biodiesel product.

References

- Arshad, M., Bano, I., Khan, N., Shahzad, M.I., Younus, M., Abbas, M., and Iqbal, M. (2018). Electricity generation from biogas of poultry waste: An assessment of potential and feasibility in Pakistan. *Renew. Sust. Energ. Rev.*, 81:1,241-1,246.
- Che, F., Sarantopoulos, I., Tsoutsos, T., and Gekas, V. (2012). Exploring a promising feedstock for biodiesel production in Mediterranean countries: A study on free fatty acid esterification of olive pomace oil. *Biomass Bioenergy*, 36:427-431.
- Chen, G., Shan, R., Shi, J., and Yan, B. (2014). Ultrasonic-assisted production of biodiesel from transesterification of palm oil over ostrich eggshell-derived CaO catalysts. *Bioresour. Technol.*, 171:428-432.
- Department of Livestock Development, Ministry of Agriculture and Cooperatives. Available from: <http://www.oic.go.th/FILEWEB/CABINFOCENT/ER28/DRAWER090/GENERAL/DATA0000/00000061.PDF>. Accessed date: 11.02.18.
- Ezekannagha C.B., Ude C.N., and Onukwuli, O.D. (2017). Optimization of the methanolysis of lard oil in the production of biodiesel with response surface methodology. *Egypt. J. Pet.*, 26:1,001-1,011.
- Giakoumis, E.G. and Sarakatsanis, C.K., (2018). Estimation of biodiesel cetane number, density, kinematic viscosity and heating values from its fatty acid weight composition. *Fuel*, 222:574-585.
- Hong, I.K., Lee, J.R. and Lee, S.B. (2015). Fuel properties of canola oil and lard biodiesel blends: Higher heating value, oxidative stability, and kinematic viscosity. *J. Ind. Eng. Chem.* 22:335-340.
- Huang, D., Zhou, H., and Lin. L. (2012). Biodiesel: An alternative to conventional fuel. *Energy Procedia*, 16:1,874-1,885.
- Huppa, A.M., Perron, J., Roques, N., Crandall, J., Ramos, S., and Rohrback, B. (2018). Analysis of biodiesel-diesel blends using ultrafast gas chromatography (UFGC) and chemometric methods: Extending ASTM D7798 to biodiesel. *Fuel*, 231:264-270.
- Jose, D.F.M., Prasad, B.D., Raj, R.E., and Kennedy, Z.R., (2014). An extraction and performance analysis of rubber seed-methyl ester on an IC engine at various

- compression ratios. *Int. J. Green Energy*, 11(8):808-821.
- Knothe, G. and Razon, L. (2017). Biodiesel fuels. *Prog. Energy Combust. Sci.*, 58:36-59.
- Niju, S., Meera, K.M., Begum, S. and Anantharaman, A. (2014). Modification of egg shell and its application in biodiesel production. *J. Saudi. Chem. Soc.*, 18:702-706.
- Ramadhas, A.S., Jayaraj, S., and Muraleedharan, C. (2005). Biodiesel production from high FFAs rubber seed oil. *Fuel*, 84:335-340.
- Rohman, A., Triyana, K., Sisindari and Erwanto, Y. (2012). Differentiation of lard and other animal fats based on triacylglycerols composition and principal component analysis. *Int. Food. Res. J.* 19(2):475-479.
- Roschat, W., Siritanon, T., Kaewpuang, T., Yoosuk, B., and Promarak, V. (2016). Economical and green biodiesel production process using river snail shells-derived heterogeneous catalyst and co-solvent method. *Bioresour. Technol.*, 209:343-350.
- Roschat, W., Siritanon, T., Yoosuk, B., Sudyoasuk, T., and Promarak, V. (2017). Rubber seed oil as potential non-edible feedstock for biodiesel production using heterogeneous catalyst in Thailand. *Renew. Energy*, 101:937-944.
- Roschat, W., Najai, K., Kaewpuang, T., and Moonsin, P. (2017). Biodiesel production via ethanolysis catalyzed by CaO derived from eggshell as low-cost basic heterogeneous catalyst. *J. Mater. Sci. App. Energy.*, 6(3):220-225.
- Roschat, W., Phewphong, S., Najai, K., Moonsin, P., and Thangthong, A. (2018). The optimized conditions of ethanolysis reaction of palm oil to biodiesel product using eggshells-derived CaO as a solid heterogeneous catalyst. *J. Mater. Sci. App. Energy.*, 7(2):295-299.
- Roschat, W., Phewphong, S., Thangthong, A., Moonsin, P., Yoosuke, B., Kaewpuang, T., and Promarak, V. (2018). Catalytic performance enhancement of CaO by hydration-dehydration process for biodiesel production at room temperature. *Energy Convers. Manage.*, 165:1-7.
- Sahar, Sadaf, S., Iqbal, J., Ullah, I., Bhatti, H.N., Nouren, S., Rehman, H., Nisar, J., and Iqbal, M. (2018). Biodiesel production from waste cooking oil: An efficient technique to convert waste into biodiesel. *Sustain. Cities Soc.*, 41:220-226.
- Shimamoto, G.G., Bianchessi, L.F. and Tubino, M. (2017). Alternative method to quantify biodiesel and vegetable oil in diesel biodiesel blends through ¹H-NMR spectroscopy. *Talanta*, 168:121-125.
- Sivakumar, P., Anbarasu, K. and Renganathan, S. (2011). Biodiesel production by alkali catalyzed transesterification of dairy waste scum. *Fuel*, 90:147-151.
- Supamathanon, N., Wittayakun, J., and Prayoonpokarach, S. (2011). Properties of Jatropha seed oil from Northeastern Thailand and its transesterification catalyzed by potassium supported on NaY zeolite. *J. Ind. Eng. Chem.*, 17:182-185.
- Vega-Lizama, T., Díaz-Ballote, L., Hernández-Mézquita, E., May-Crespo, F., Castro-Borges, P., Castillo-Atoche, A., González-García, G., and Maldonado, L. (2015). Thermogravimetric analysis as a rapid and simple method to determine the degradation degree of soy biodiesel. *Fuel*, 2015:156-158.
- Viriya-empikul, N., Krasae, P., Nualpaeng, W., Yoosuk, B., and Faungnawakij, K., (2012). Biodiesel production over Ca-based solid catalysts derived from industrial wastes. *Fuel*, 92:239-244.
- Winayanuwattikun, P., Kaewpiboon, C., Piriayakananon, K., Tantong, S., Thakernkamkit, W., Chulalaksanankul and Yongvanich, W. (2008). Potential plant oil feedstock for lipase-catalyzed biodiesel production in Thailand. *Biomass Bioenergy*, 32:1,279-1,286.
- Yadav, M., Singh, V., and Sharma, Y.C. (2017). Methyl transesterification of waste cooking oil using a laboratory synthesized reusable heterogeneous base catalyst: Process optimization and homogeneity study of catalyst. *Energy Convers. Manage.*, 148:1,438-1,452.