Acta Technologica Agriculturae 4
Nitra, Slovaca Universitas Agriculturae Nitriae, 2021, pp. 153–158

BIODIESEL PRODUCTION FROM WASTE FRYING OILS BY POTASSIUM METHOXIDE SUPPORTED ON ACTIVATED CARBON CATALYSTS FROM LIGNOCELLULOSIC BIOMASS

DARWIN*, Atmadian PRATAMA, MARDHOTILLAH

Universitas Syiah Kuala, Banda Aceh, Indonesia

Various carbon-rich solid catalysts are evaluated for the synthesis of biodiesel from waste frying oil. The study results showed that the use of activated carbon made of corn stalk could increase the biodiesel yield by 7%. The heterogeneous carbon-based catalysts made of lignocellulosic residues could successfully improve the quality of biodiesel properties. The results obtained revealed that the biodiesel properties, including relative density ($852\text{--}900\text{ kg}\cdot\text{m}^{-3}$) and kinematic viscosity ($2.4\text{--}3.9\text{ mm}^2\cdot\text{s}^{-1}$), are in compliance with the standard limits of ASTM and the European Biodiesel Standard, suggesting that the biodiesel produced would be decent as a diesel fuel that potentially can minimize the serious damage of engine parts, and prolong the engine life.

Keywords: transesterification; lignocellulosic residues; carbon-based solid catalyst

Global energy depletion, increased demand for non-renewable energy, increasing cost of fossil fuels, climate change and global warming due to greenhouse gas emissions represent the main factors leading to search for sustainable and renewable energy alternatives (Jacobson et al., 2008; Abbaszaadeh et al., 2012; Darwin et al., 2017). Currently, approx. 90% of energy being used worldwide and almost 100% of energy used in transportation comes from non-renewable fossil fuels (Abbaszaadeh et al., 2012). Utilization of alternative non-fossil fuels for meeting the demand of transportation and industrial sectors is an urgent matter that requires dealing with due to the depletion of fossil fuels, as well as the reduction of environmental pollution caused by burning of fossil fuels (Liu et al., 2007; Gontupil et al., 2012; Darwin et al., 2016).

Biodiesel is sustainable clean biofuel that can be produced from vegetable oils and/or animal fats via transesterification process. It is a non-petroleum-based fuel containing alkyl esters. Since biodiesel has similar characteristics with petroleum diesel, it can serve as potential alternative used for fuelling diesel engines. As an alternative diesel fuel, it has certain benefits, e.g., lower emissions, better lubricity, higher cetane number, non-toxic, biodegradability, improved combustion reaction, and higher efficiency in the operated diesel engines (Peng, 2015; Kumar et al., 2018; Kapilan and Reddy, 2020). Even though it can be potential alternative fuel, its utilization as a fuel has not been widely accepted worldwide. This is because its market price is still more expensive in comparison to the conventional petroleum diesel. The major impediments for commercialization and scaling up the massive biodiesel production are the production costs (Jacobson et al., 2008; Karmee et al., 2015).

Certain factors affecting the biodiesel production costs include feedstock or raw materials, chemical solvents, catalysts and purification processes. In the commercial biodiesel production, the feedstock usually contributes to almost 80% of the total biodiesel production costs (Demirbas, 2007; Karmee et al., 2015). An alternative cheap feedstock, such as waste frying oils (WFO), is valuable, since its utilization as a biodiesel feedstock could significantly lower the biodiesel production costs. Hence, it could reduce its price in the global market, sustain its production, and cut the dependency on petroleum diesel (Khan et al., 2019).

Biodiesel synthesis using WFO as feedstock is a challenging task as it typically contains some undesirable components, i.e., free fatty acids (FFA) and water (Jacobson et al., 2008). Several studies (Demirbas, 2009; Hoang et al., 2013) reported that the feedstock containing a significant amount of FFA and water may inhibit the transesterification process to optimize biodiesel production. This is because FFA would react with the catalyst to form soap and inhibit the separation of biodiesel from glycerol. Transesterification of WFO using homogeneous alkali catalyst would result in undesirable reaction of saponification, and thereby could lower the methyl ester yield. Moreover, usage of homogeneous catalysts (i.e. sodium hydroxide and potassium hydroxide) in the transesterification process would have some drawbacks in regards to catalyst reusability and its separation from the methyl ester. The use of heterogeneous catalysts for transesterification provides specific benefits, such as an easy separation and reuse, and soap formation reduction (Hoang et al., 2013).

Currently, the use of carbon-based catalyst (i.e. activated carbon and biochar) as a renewable heterogeneous catalyst made of lignocellulosic biomass is of great significance as

Contact address: Darwin, Universitas Syiah Kuala, Department of Agricultural Engineering, Banda Aceh 23111, Indonesia; e-mail: darwin_ae@unsyiah.ac.id

it can highly contribute to cutting the costs of biodiesel production (Konwar et al., 2012; Jamil et al., 2020). Several studies (Azargohar and Dalai, 2006; Konwar et al., 2012) revealed that carbon-based materials can be used as catalyst supports as they have potential characteristics, including high stability in acid and basic media and possibility of adjusting their texture and surface chemistry. The study purposed aims to evaluate the utilization of heterogeneous catalysts of carbon-rich solid derived from various lignocellulosic wastes used as renewable catalysts for transesterification of WFO to enhance the formation and yield of biodiesel. The utilization effects of heterogeneous catalysts on the WFO transesterification towards the biodiesel parameters are also evaluated.

Material and methods

Materials preparation

The waste frying oils (WFO) used for the current study was taken from the Kentucky Fried Chicken (KFC) restaurants located in Banda Aceh, Indonesia. Shortly after collecting them, they were cleaned and filtered to get rid of any particle impurities, such as leftover fried foods or other particles that may affect the transesterification reactions for biodiesel production. The cleaned WFO was subsequently stored in a glass bottle and kept at ambient temperature (29 ± 2 °C). Prior to experiments, the oil sample was put in a flask and heated at a temperature of 107 ± 3 °C to evaporate the water contained. To get rid of any particle impurities, the oil sample was refined using a 200 mesh-screen (Darwin et al., 2020).

Preparation of heterogeneous catalyst

The heterogeneous catalyst used for this experiment was an activated carbon made of the lignocellulosic biomass. The biomass included rice husk (RH), coconut shell (CS), cocoa husk (CH) and corn stalk (CST), in which the carbonization process was carried out through the process of fast pyrolysis. The biomass was impregnated with NaOH at a temperature of 450–550 °C before the carbonization process. After cooling, the activated carbon of biomass was continually washed with distilled water up to a neutral pH. The washed activated carbon was dried at 107 ± 3 °C for 10 to 12 h. Then it was cooled in a desiccator and kept in a glass container until use (Buasri et al., 2012). For preparing the heterogeneous catalyst, 0.1 M of potassium hydroxide was dissolved with distilled water in order to achieve a 1.5 litre solution. Subsequently, 100 g of activated carbon was added to the alkaline solution to produce a standard heterogeneous catalyst of transesterification reaction. The prepared heterogeneous catalyst was continuously mixed at 50 rpm at a room temperature for 24 h (Darwin et al., 2020).

Transesterification reaction procedure

The transesterification reaction was conducted using 99% methanol (an analytical grade) as a solvent. Subsequently, 4 g of potassium hydroxide was dissolved in 100 ml of the solvent to have a methoxide solution. The prepared solution was mixed with 300 ml of WFO in a ratio of 1 : 3

(100 ml methoxide + 300 ml WFO). Afterwards, 10 g of the activated carbon of biomass were added to the mixture, which was subsequently mixed at 50 rpm for approx. 24 h. The process was maintained at 35 °C in order to separate the crude glycerine and crude biodiesel. The yellow clear oil in top layer was biodiesel that would be harvested and/or separated from the glycerine in the bottom layer.

Separation process was carefully carried out using a syringe and/or a gravity method. Subsequent to the separation, the crude biodiesel was washed with 1 l of distilled water to clean it from the soap component as a transesterification by-product. During washing, the vessel with the mixture was circulated using an air pump. The crude biodiesel was removed from the mixture using the gravity method. The clean biodiesel was purified by heating it at 105 ± 5.0 °C to get rid of the impurities (Darwin et al., 2020; El-Gharbawy et al., 2021).

Analytical methods

The biodiesel produced was analysed to assess its relative density, free fatty acid (FFA) content, water content, acid number, conductivity, flash point, and viscosity. Analysis of relative density was carried out using a pycnometer at the temperature of 15 °C. Result from the mass difference between the pycnometer with biodiesel and empty pycnometer was then divided by the biodiesel volume to obtain the value of relative density. Viscosity measurement was performed using a vertical falling sphere viscometer equipped with digital timer at 40 °C (Yuan and Lin, 2008). Measurements of FFA and acid content were performed utilizing a pH metre multifunction model benchtop complete probe and burette tube filled with 100 mM of potassium hydroxide (KOH). Prior to the analysis, the analyte was dropped with phenolphthalein indicator solution (Darwin and Bignaut, 2019).

Biodiesel conductivity was measured by alab benchtop conductivity metre, and to ensure accurate and reproducible results, the conductivity meter was calibrated with potassium chloride (KCl) standard solution prior to analysis. The WFO used as biodiesel feedstock and biodiesel samples were analysed for their pH using a laboratory benchtop pH meter based on the standard methods (Rice et al., 2017).

Water content was analysed by a lab heating and drying oven, in which the sample was heated for approx. 24 hours at 105 °C (Rice et al., 2017). Measurement of flash point was performed using a laboratory hot plate equipped with thermocouple. The biodiesel sample was kept inside the flash point apparatus with a cotton thread, and heated with the hot plate (Karmakar et al., 2018). To determine the conversion effectiveness of WFO during the transesterification reaction, the resultant products were divided on the basis of the raw material used to evaluate the yield of biodiesel as its main product, and glycerine as by-product. To ensure the accuracy of data analysis, all sample measurements were conducted in triplicates. All biodiesel parameters were measured according to the Standards and Testing Methods ASTM D6751 (Burton, 2008).

Results and discussion

The study evaluates biodiesel synthesis using different types of renewable heterogenous catalysts derived from lignocellulosic wastes. Parameters of biodiesel affected by the use of carbon-based catalysts in the transesterification process were also investigated. The properties of the WFO used are shown in Table 1. The physicochemical properties of feedstock include a density of $850 \text{ kg}\cdot\text{m}^{-3}$, a viscosity of $4.2 \text{ mm}^2\cdot\text{s}^{-1}$ and FFA of 1.7%.

Table 1 Characteristics of WFO as raw material for biodiesel synthesis

Parameters	Unit	Waste frying oil
pH	–	5.20 ± 0.185
Water content	%	5.01 ± 0.010
Relative density at 15°C	$\text{kg}\cdot\text{m}^{-3}$	850 ± 0.550
Kinematic viscosity at 40°C	$\text{mm}^2\cdot\text{s}^{-1}$	4.17 ± 0.011
FFA	%	1.72 ± 0.018
Acid number	$\text{mg KOH}\cdot\text{g}^{-1}$	3.42 ± 0.017
Electrical conductivity	$\text{mS}\cdot\text{m}^{-1}$	0.11 ± 0.015

The results show that activated carbon made of lignocellulosic biomass used as heterogeneous catalyst for transesterification process could affect the biodiesel yield (Fig. 1). In this process, methoxide solution was introduced to each mixture in the transesterification chamber to accelerate the transesterification reaction to form methyl ester as the end-product. Results indicate that the transesterification process using activated carbon catalyst made of corn stalk showed higher biodiesel yield (85%) compared to other tested samples (55–78%).

This agrees with the study by Konwar et al. (2012) revealing that the use of a heterogeneous catalyst can enhance the biodiesel yield by 96%, which is somewhat higher than the result obtained in this study. The different results could be attributed to the different types of heterogenous catalysts used for transesterification, in which the authors used biochar derived from waste shells of *T. striatula*, while the current study used biochar made of corn stalk.

Fig. 1 Biodiesel yield using various lignocellulosic biomass catalysts

The results obtained reveal that the transesterification process of WFO using various types of heterogeneous biomass catalysts tends to generate more glycerine compared with the control sample. As depicted in Fig. 2, the majority of the heterogeneous catalyst samples made of rice husk (RH), coconut shell (CS), and cocoa husk (CH) generates higher glycerine yields (60–80%), while another heterogeneous catalyst made of corn stalk (CST) produces less glycerine (48%). This suggested that the heterogeneous catalysts of carbon-rich solid made of corn stalk is more feasible to be used as a heterogeneous catalyst for the transesterification of WFO as it could enhance the biodiesel yield (Fig. 1) and lower the formation of glycerine as a by-product.

The results agree with some studies reporting that in the process of transesterification for biodiesel synthesis normally generates the glycerine as between 30 and 60% (Gomes et al., 2010; Hájek and Skopal, 2010; Ondul and Dizge, 2014). The formation of glycerine as a by-product during the transesterification process of vegetable and animal oils is inevitable. This is because typically around 10% of glycerine would be produced for each ton of the biodiesel synthesis (Singhabhandhu and Tezuka, 2010; McNeil et al., 2012; Ondul and Dizge, 2014).

Furthermore, the results suggest that biodiesel production using the heterogeneous catalysts of lignocellulosic biomass origin produced more FFA (2.50–3.11%) in contrast to the control (C) sample not using the heterogeneous catalyst tested (2.07%). This indicates that the use of heterogeneous catalyst may enhance the fatty acid accumulation in the WFO transesterification. Torres et al. (2013) observed that a high FFA content indicates that triglycerides in the mixture of WFO and methoxide solution are not completely reacted in producing biodiesel; all triglycerides should be fully esterified during the transesterification process, otherwise it could lower and deteriorate the biodiesel quality as a fuel.

Moreover, the use of activated carbon made of lignocellulosic biomass as co-catalyst in the WFO transesterification could enhance the FFA in the biodiesel synthesized (Fig. 3). As the WFO transesterification was carried out at an ambient temperature, the solubility of mixture between the WFO and methoxide could be hindered even though the mixtures were continuously mixed. This agrees with the research presented by Karki et

Fig. 2 Glycerine yield using various lignocellulosic biomass catalysts

Fig. 3 Free fatty acid (FFA) content in case of using lignocellulosic biomass catalysts

Fig. 5 Relative density of biodiesel using heterogeneous catalyst of lignocellulosic biomass

Fig. 4 Electrical conductivity of biodiesel using heterogeneous lignocellulosic biomass catalysts

Fig. 6 Viscosity of biodiesel using heterogeneous catalyst of lignocellulosic biomass

al. (2017), who reported that the transesterification process using methanol as a solvent may not be easily dissolved with triglycerides at a room temperature, and typically would form emulsions during the reaction.

The electrical conductivity measurement of synthesized biodiesel was carried out to assess the biodiesel's ability to dissipate any electrical charges (Kinast, 2003). The results acquired revealed that usage of heterogeneous carbon-based catalysts generates a higher conductivity value (0.03–0.04 mS·m⁻¹) of the synthesized biodiesel compared to the control sample (0.02 mS·m⁻¹). As shown in Fig. 4, the sample of a heterogeneous catalyst of RH had the highest conductivity value of the produced biodiesel (0.04 mS·m⁻¹). This suggests that the activated carbon made of rice husk used as heterogeneous catalyst can successfully enhance the conductivity of produced biodiesel. This is of substantial significance since, at a low conductivity, biodiesel electrical charges could easily accumulate, and thereby may cause a dissipation heat in the form of a spark (Leonard, 1981; Darwin et al., 2020).

The study presented found that the biodiesel density obtained using the heterogeneous catalyst of lignocellulosic wastes is lower (842–890 kg·m⁻³) in contrast to the biodiesel without using the heterogeneous catalyst (896 kg·m⁻³). As depicted in Fig. 5, the results show that the density of produced biodiesel catalysed with the lignocellulosic biomass is somewhat close to the petroleum diesel density that is approx. 832 kg·m⁻³. This indicates that the biodiesel produced would have a fine atomization and a consummate

combustion inside the engine, prolonging thus an engine life (Prankl et al., 2004; Pratas et al., 2010). Additionally, the density of synthesized biodiesel falls within the standard limits of the American Society for Testing and Materials (ASTM) extended between 860 kg·m⁻³ and 900 kg·m⁻³ (Knothe, 2006; Verduzco, 2013; Karmakar et al., 2018). Furthermore, the density of biodiesel acquired is still in the conforming range of the European Standard for Biodiesel (EN 14214), in which the threshold values of the methyl ester density for effective operating diesel engines range from 0.86 to 0.9 g·cm⁻³ (Darwin et al., 2020).

Viscosity greatly determines the synthesized biodiesel quality as a proper diesel fuel (Verduzco, 2013). As shown in Fig. 6, the study results reveal that the viscosity of synthesized biodiesel using the heterogeneous catalysts made of lignocellulosic biomass of cocoa husk and corn stalk is quite lower (2.5–3.0 mm²·s⁻¹) in contrast to the control sample (3.10 mm²·s⁻¹). The viscosity of produced biodiesel is highly influenced by the feedstocks used in the process of transesterification (Pratas et al., 2010; Verduzco, 2013).

The results obtained show that obtained biodiesel just falls within the standard limits of the ASTM extending outward from 1.9 mm²·s⁻¹ to 6.0 mm²·s⁻¹. Moreover, the results acquired are mostly lower in comparison to values determined by the European Biodiesel Standard limits, which are between 3.5 mm²·s⁻¹ and 5.0 mm²·s⁻¹ (Knothe and Steitldley, 2005). Only the sample catalysed with the heterogeneous catalyst made of coconut shell complies with the European Biodiesel Standard limits (3.94 mm²·s⁻¹).

Table 2 Physicochemical properties of biodiesel made of different heterogeneous catalyst of lignocellulosic biomass

Parameter	C	RH	CS	CH	CST
pH	8.51 ±0.02	8.13 ±0.01	8.16 ±0.02	8.01 ±0.01	8.13 ±0.01
Water content (%)	4.434 ±0.115	11.73 ±0.02	3.728 ±0.012	6.993 ±0.015	6.721 ±0.011
Acid number (mg KOH·g ⁻¹)	4.121 ±0.012	5.316 ±0.025	5.732 ±0.018	4.895 ±0.015	6.194 ±0.011
Flash point (°C)	82.3 ±0.11	80 ±0.05	74 ±0.15	85 ±0.11	83.4 ±0.55

The lower biodiesel viscosity is more favourable if the fuel is used as a diesel fuel because the lower biodiesel viscosity may minimize the risks arising when it fuels the diesel engines. Further problems that could be minimized include incomplete combustion, ring carbonization, wear in the fuel pump elements and clogging of fuel injectors. These arise due to the higher viscosity of biodiesel causing extreme increase of the fuel injection pressure, resulting in a greater droplet up, higher energy requirements of the pumps, and leading to a severe fuel spray (Baroutian et al., 2010; Yuan et al., 2009; Xue et al., 2011).

The current study reveals that the biodiesel synthesized using the lignocellulosic biomass catalysts does not significantly increase its flashpoint (Table 2). On average, the flashpoint of the biodiesel synthesized using a heterogenous carbon-based catalyst made of lignocellulosic wastes such as rice husk, coconut shell, cocoa husk and corn stalk, ranged from 74 °C to 85 °C, while the flashpoint of control sample was approx. 82 °C. These flashpoints are much lower than the minimum standard limits determined by the ASTM standard (approx. 93 °C) (Karmakar et al., 2018). The low biodiesel flash point may maximize the chance of unexpected fire hazard (Prankl et al., 2004), and thereby a safety precaution should be carefully taken, and/or properly mixing it with the petro-diesel prior to using it as a diesel fuel.

Conclusions

The carbon-based catalyst made of corn stalk could generate higher biodiesel yield (85%) in comparison to the other samples. The quality of biodiesel properties, such as relative density and kinematic viscosity, could be improved by the heterogeneous carbon-based catalysts during the transesterification process. The average overall viscosity (3.03 mm²·s⁻¹) and density (866 kg·m⁻³) achieved are quite close to the European Biodiesel Standard and ASTM standard. The current study shows that the low flash point of achieved results (<90 °C) should be improved in order to meet the standards (93 °C) and lower the risk of unexpected fire hazard.

Acknowledgments

The authors thank to Universitas Syiah Kuala, Banda Aceh, Indonesia for funding the research through the scheme of H-Index research programme (grant number: 290/UN11.2.1/PT.01.03/PNBP/2021) led by the Institute for Research and Community Services, USK.

References

ABBASZADEH, A. – GHOBADIAN, B. – OMIDKHAH, M. R. – NAJAFI, G. 2012. Current biodiesel production technologies: A comparative

review. In *Energy Conversion and Management*, vol. 63, pp. 138–148.

AZARGOHAR, R. – DALAI, A. K. 2006. Biochar as a precursor of activated carbon. In *Twenty-Seventh Symposium on Biotechnology for Fuels and Chemicals*. Totowa, New Jersey :Humana Press, pp. 762–773. ISBN 9781588298669.

BAROUTIAN, S. – AROUA, M. K. – RAMAN, A. A. A. – SULAIMAN, N. M. N. 2010. Viscosities and densities of binary and ternary blends of palm oil+ palm biodiesel+ diesel fuel at different temperatures. In *Journal of Chemical & Engineering Data*, vol. 55, no. 1, pp.504–507.

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. In *Korean Journal of Chemical Engineering*, vol. 29, pp. 1708–1712.

BURTON, R. 2008. An Overview of ASTM D6751: Biodiesel Standards and Testing Methods. Sanford : Alternative Fuels Consortium, Central Carolina Community College.

DARWIN – CHENG, J. J. – LIU, Z. – GONTUPIL, J. 2016. Anaerobic co-digestion of cocoa husk with digested swine manure: evaluation of biodegradation efficiency in methane productivity. In *Agricultural Engineering International: The CIGR Journal*, vol. 18, no. 4, pp. 147–156.

DARWIN – BLIGNAUT, D. 2019. Alkaline treatment for preventing acidosis in the rumen culture fermenting carbohydrates: An experimental study *in vitro*. In *Journal of Advanced Veterinary and Animal Research* vol. 6, no. 1, pp. 100–107.

DARWIN – FAZIL, A. – ILHAM, M. – SARBAINI – PURWANTO, S. 2017. Kinetics on anaerobic co-digestion of bagasse and digested cow manure with short hydraulic retention time. In *Research in Agricultural Engineering Journal*, vol. 63, no. 3, pp. 121–127.

DARWIN – PRATAMA, A. D. – MARDHOTILLAH. 2020. A synthesis of biodiesel on the ground of cooking oil using lignocellulosic residues as a heterogeneous catalyst and alcohol solvents. In *Journal of Chemical Technology & Metallurgy*, vol. 55, no. 4, pp. 778–784.

DEMIRBAS, A. 2007. Importance of biodiesel as transportation fuel. In *Energy Policy*, vol. 35, no. 9, pp. 4661–4670.

DEMIRBAS, A. 2009. Progress and recent trends in biodiesel fuels. In *Energy Conversion and Management*, vol. 50, no. 1, pp. 14–34.

EL-GHARBAWY, A. S. – SADIK, W. A. – SADEK, O. M. – KASABY, M. A. 2021. A review on biodiesel feedstocks and production technologies. In *Journal of the Chilean Chemical Society*, vol. 66, no. 1, pp. 5098–5109.

GOMES, M. C. S. – PEREIRA, N. C. – DE BARROS, S. T. D. 2010. Separation of biodiesel and glycerol using ceramic membranes. In *Journal of Membrane Science*, vol. 352, pp. 271–276.

GONTUPIL, J. – DARWIN – LIU, Z. – CHENG, J. J. – CHEN, H. 2012. Anaerobic co-digestion of swine manure and corn stover for biogas production. In *Annual International Meeting Conference 2012*. Dallas, Texas : American Society of Agricultural and Biological Engineers.

HÁJEK, M. – SKOPAL, F. 2010. Treatment of glycerol phase formed by biodiesel production. In *Bioresource Technology*, vol. 101, no. 9, pp. 3242–3245.

- HOANG, D. A. V. – BENSARD, S. – SARACCO, G. 2013. Supercritical fluid technology in biodiesel production. In *Green Processing and Synthesis*, vol. 2, no. 5, pp. 407–425.
- JACOBSON, K. – GOPINATH, R. – MEHER, L. C. – DALAI, A. K. 2008. Solid acid catalyzed biodiesel production from waste cooking oil. In *Applied Catalysis B: Environmental*, vol. 85, no. 1–2, pp. 86–91.
- JAMIL, F. – KUMAR, P. S. M. – AL-HAJ, L. – MYINT, M. T. Z. – ALA'A, H. A.-M. 2020. Heterogeneous carbon-based catalyst modified by alkaline earth metal oxides for biodiesel production: Parametric and kinetic study. In *Energy Conversion and Management: X*, vol. 10, article no. 100047.
- KARKI, N. – SANJEL, N. – POUDEL, J. – CHOI, J. H. – OH, S. C. 2017. Supercritical transesterification of waste vegetable oil: characteristic comparison of ethanol and methanol as solvents. In *Applied Sciences*, vol. 7, no. 6, article no. 632.
- KARMAKAR, R. – KUNDU, K. – RAJOR, A. 2018. Fuel properties and emission characteristics of biodiesel produced from unused algae grown in India. In *Petroleum Science*, vol. 15, pp.385–395.
- KARME, S. K. – PATRIA, R. D. – LIN, C. S. K. 2015. Techno-economic evaluation of biodiesel production from waste cooking oil – a case study of Hong Kong. In *International Journal of Molecular Sciences*, vol. 16, no. 3, pp. 4362–4371.
- KHAN, H. M. – ALI, C. H. – IQBAL, T. – YASIN, S. – SULAIMAN, M. – MAHMOOD, H. – RAASHID, M. – PASHA, M. – MU, B. 2019. Current scenario and potential of biodiesel production from waste cooking oil in Pakistan: An overview. In *Chinese Journal of Chemical Engineering*, vol. 27, no. 10, pp. 2238–2250.
- KINAST, J. A. 2003. Production of biodiesels from multiple feedstocks and properties of biodiesels and biodiesel/diesel blends. Colorado : National Renewable Energy Laboratory, 45 pp.
- 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. In *Fuel*, vol. 84, no. 9, pp. 1059–1065.
- KNOTHE, G. 2006. Analyzing biodiesel: standards and other methods. In *Journal of the American Oil Chemists' Society*, vol. 83, pp. 823–833.
- KONWAR, L. J. – CHUTIA, S. – BORO, J. – KATAKI, R. – DEKA, D. 2012. Biochar supported Cao as heterogeneous catalyst for biodiesel production. In *International Journal of Innovative Research and Development*, vol. 1, no. 7, pp. 186–195.
- KUMAR, N. – SONTALIA, A. – PALI, H. S. 2018. Alternative fuels for diesel engines: New frontiers. In *Diesel and Gasoline Engines*. London : IntechOpen. ISBN 9781789854473. Available at: <https://www.intechopen.com/books/diesel-and-gasoline-engines/alternative-fuels-for-diesel-engines-new-frontiers>
- LEONARD, J. T. 1981. Generation of Electrostatic Charge in Fuel Handling Systems: A Literature Survey (NRL Report 8484). Washington DC : Naval Research Laboratory, 55 pp.
- LIU, L. – CHENG, S. Y. – LI, J. B. – HUANG, Y. F. 2007. Mitigating environmental pollution and impacts from fossil fuels: The role of alternative fuels. In *Energy Sources, Part A*, vol. 29, no. 12, pp.1069–1080.
- MCNEIL, J. – DAY, P. – SIROVSKI, F. 2012. Glycerine from biodiesel: The perfect diesel fuel. In *Process Safety and Environmental Protection*, vol. 90, no. 3, pp. 180–188.
- KAPILAN, N. – REDDY, R. P. 2020. Effect of basil oil on the performance of biodiesel fuelled agricultural engine. In *Acta Technologica Agriculturae*, vol. 23, no. 4, pp.155–160.
- ONDUL, E. – DIZGE, N. 2014. Glycerol: A major by-product in the biodiesel manufacturing process. In *Yüzüncü Yıl Üniversitesi Fen Bilimleri Enstitüsü Dergisi/Journal of The Institute of Natural & Applied Sciences*, vol. 19, no. 1–2, pp. 75–79.
- PENG, D. X. 2015. Effects of concentration and temperature on tribological properties of biodiesel. In *Advances in Mechanical Engineering*, vol. 7, no. 11.
- PRATAS, M. J. – FREITAS, S. – OLIVEIRA, M. B. – MONTEIRO, S. C. – LIMA, A. S. – COUTINHO, J. A. P. 2010. Densities and viscosities of fatty acid methyl and ethyl esters. In *Journal of Chemical & Engineering Data*, vol. 55, no. 9, pp. 3983–3990.
- RICE, E. W. – BAIRD, R. B. – EATON, A. D. 2017. Standard Methods for the Examination of Water and Wastewater. 23rd edition. Washington, D.C. : American Public Health Association, 1796 pp. ISBN 9780875532875.
- SINGHABHANDHU, A. – TEZUKA T. 2010. A perspective on incorporation of glycerine purification process in biodiesel plants using waste cooking oil as feedstock. In *Energy*, vol. 35, no. 5, pp. 2493–2504.
- TORRES, C. M. – RÍOS, S. D. – TORRAS, C. – SALVADÓ, J. – MATEO-SANZ, J. M. – JIMÉNEZ, L. 2013. Sustainability analysis of biodiesel production from *Cynara Cardunculus* crop. In *Fuel*, vol. 111, pp. 535–542.
- VERDUZCO, L. F. R. 2013. Density and viscosity of biodiesel as a function of temperature: Empirical models. In *Renewable and Sustainable Energy Reviews*, vol. 19, pp. 652–665.
- PRANKL, H. – KÖRBITZ, W. – MITTELBACH, M. – WÖRGETTER, M. 2004. Review on biodiesel standardization world-wide. In Prepared for IEA Bioenergy Task 39, Subtask "Biodiesel". Wieselburg : BLT – Bundesanstalt für Landtechnik, 75 pp.
- XUE, J. – GRIFT, T. E. – HANSEN, A. C. 2011. Effect of biodiesel on engine performances and emissions. In *Renewable and Sustainable Energy Reviews*, vol. 15, no. 2, pp. 1098–1116.
- YUAN, W. – HANSEN, A. C. – ZHANG, Q. 2009. Predicting the temperature dependent viscosity of biodiesel fuels. In *Fuel*, vol. 88, no. 6, pp.1120–1126.
- YUAN, P. – LIN, B. Y. 2008. Measurement of viscosity in a vertical falling ball viscometer. In *American Laboratory*, vol. 40, pp. 32–35.