Biodiesel production from castor oil and analysis of its physical properties

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Abstract

Biodiesel is a biodegradable, renewable energy and efficient substitution fuel which can fulfill energy security needs without sacrificing engine performance. Biodiesel fuels were prepared from vegetable oil of castor beans and its physical properties such as viscosity, flash point and pour point were studied. The crude castor oil was purified and trans-esterified. Transesterification reaction is most widely used method for biodiesel production, in which the triglycerides in the oil reacts with monohydric alcohol. 200 ml of the castor oil was measured and pre-heated to 70 ^{o}C using hot magnet stirrer with thermometer. 1.5 ml citric acid was added to the heated oil sample and continuously stirred for 15 minutes at 70 ^{o}C. 4g of 8 % KOH was then added to the oil and continuously heated and stirred for 15 minutes at 70 ^{o}C. The mixture was then transferred to the vacuum oven where it was heated at 85 ^{o}C for 30 minutes. Similarly, 2g of silicon reagent was added while it was being heated and stirred. after 30 minutes the temperature was increased to 85 ^{o}C and 4g of activated carbon was added to each 100 ml of the oil sample, heated and stirred for 30 minutes and the mixture was separated using filter paper. At 30, 60 and 90 ^{o}C, the viscosity of crude, purified and transesterified castor oil were found to be (64, 52, 50 mpa.s), (47, 43, 37 mpa.s) and (38, 35 and 30 mpa.s) respectively. This shows that, trans-esterified castor oil has viscosities within similar range with the crude biodiesel oil for all the varying temperatures, indicating that viscosity is major reason why oils and fats are trans-esterified to biodiesel.

***Keywords*:** Biodiesel, castor oil, esterification and Trans-esterification.

Introduction

Biodiesel is an alternative fuel which is suitable for use in diesel engine. It is a mixture of long chain fatty acids methyl ester (FAME) derived from renewable lipid source such as vegetable oil and animal fat, which can be used in compression or on modification (Demirbas, 2009). Biodiesel can be obtained from vegetable oil and animal fats using trans-esterification method. It is a non-fossil fuel alternative to Petrol/diesel and it is domestically produced. Biodiesel is clean on burning and renewable substitute for petroleum diesel. Use of biodiesel as vehicle fuel increases energy security, improves air quality. Biodiesel in its pure unblended form causes far less damage than petroleum diesel if it released to the environment. Consequently, it is safe to handle, stored and transport. Biodiesel generates less greenhouse gas and toxic pollutants. It helped several countries in reducing their dependence on foreign oil reserves. Biodiesel helps to increases the cetane number of fuel lubricity, it makes the engine work more smoothly and more effectively. It is also environment friendly and economical. It has many important technical advantages over conventional diesel such as inherent lubricity, low toxicity, derived from a renewable and domestic feedstock, superior flash points, negligible Sulphur content and lower exhaust emission (Moser, 2009).

Biodiesel has been widely used as a blend with diesel. The use of biodiesel as a diesel blend will promote cleaner emission with less sort particles and whiter smoke. Biodiesel works in existing diesel engine with no modification. It can achieve emission reduction across the entire diesel. Biodiesel has outstanding cleaning properties. It has low toxic emission and particulate matter. Biodiesel is safe to store and has high flash point. Similarly, use of biodiesel requires no engine modification and does not affect engine performance. Because of different climate condition various countries are using nonedible oils for production of biodiesel. Utilization of biodiesel has many technical, economic and environmental advantage. It also emerged a promising alternative to Petro diesel because of its remarkable characteristics such as biodegradability, less toxicity and reduced greenhouse gas emission. It can also be used as blending component for diesel fuel in automotive engine (Gupta, 2003).

Biodiesel is obtained from different triglyceride sources as an alternative fuel to Petro-diesel. The American Society for Testing and Materials (ASTM) defines biodiesel as mono-alkyl esters produced from various lipid feedstock including vegetable oils, animal fats, etc. Furthermore, it has been accepted as a fuel additive worldwide and registered with the U.S. Environmental Protection Agency (EPA). Owing to the worries about petroleum availability and the current increase in petroleum price, the usage of biodiesel in conventional diesel engines has attracted much attention.

The history of biodiesel began in the 1900s when Sir Rudolf Diesel successfully ran conventional diesel engines using vegetable oil without any modification. In the 1930s and 1940s, vegetable oil was utilized as diesel fuel, particularly in the emergencies. However, further investigation has verified that, the direct usage of vegetable and animal oils as diesel fuel is impractical due to their large molecular mass, low volatility, and high kinematic viscosity, which reduce the performance of the engine and raise other problems including thickening, gelling, and

sticking of the oil. To overcome these problems and allow its application as a fuel, research used the process of trans-esterification to produced biodiesel (Zahan etal., 2018).

Due to the increase in price of petroleum and environmental concern about pollution coming from automobile emission, the world is confronted with the twin crises of fossil fuel depletion and environmental degradation. Biodiesel promises to harmonize sustainable development, management, energy conversion, environmental preservation and efficiency. Vegetable oil is a promising alternative to petroleum products. The economic feasibility of biodiesel depends on the price of crude petroleum and the cost of transporting diesel over long distances to remote areas (Sandeep Singh, 2007).

Castor oil is a multipurpose vegetable oil that is mainly used for thousands of years. It is a non-edible oil. Recently, nonedible oils have become attractive feedstock for diesel production, because of their low cost compared to those edible oils. The plants from which nonedible oils are obtained is easy to cultivate in lands where edible oils cannot be grown and cultivated easily. Cost for nonedible oil producing plants is much less than the cost of edible plant oil (Gui etal.,2009). It was further reported that, castor oil has high oil content (between 30% -55%).

Castor oil is considered to be one of the most promising nonedible oil crops, due to its high annual seed production and yield, since it can be grown on marginal land and in semiarid climate. According to Berman et al. (2008), it was found that methyl ester of castor oil can be used as a biodiesel alternative feedstock when blended with diesel fuel. Moreover, castor oil has long been used commercially as high renewable resource for chemical industry, it is a vegetable oil obtained by pressing the seed of castor plant.

It was reported that, castor oil seed contains about 30% – 50% oil (m/m), and can be extracted from castor beans by mechanical pressing, solvent extraction, or a combination of pressing and extraction. After harvesting, the seeds are allowed to dry so that the seed hull will split open, releasing the seed inside (Abitogun et.al; 2009). The extraction process begins with the removal of the hull from the seeds. This can be accomplished mechanically with the aid of a castor bean de-huller or manually with the hands. When economically feasible, the use of a machine to aid in the de-hulling process is more preferable (Vinay et al; 2016).

The unique structure of castor oil offers interesting properties, making it appropriate for various industrial applications. Castor oil is known to consist of up to 90% ricinoleic, 4% linoleic, 3% oleic, 1% stearic, and less than 1% linolenic fatty acids. Castor oil is valuable due to the high content of ricinoleic acid (RA), which is used in a variety of applications in the chemical industry. The hydroxyl functionality of RA makes the castor oil a natural polyol providing oxidative stability to the oil, and a relatively high shelf life compared to other oils by preventing peroxide formation. The presence of the hydroxyl group in RA and RA derivatives provides a functional group location for performing a variety of chemical reactions including halogenation, dehydration, alkoxylation, esterification, and sulfation. As a result, this unique functionality allows the castor oil to be used in industrial applications such as paints, coatings, inks, and lubricants. Castor beans, the source of

castor oil, contain some allergenic (2S albumin) proteins as well as ricin. However, processed or refined castor oil is free from any of these substances and can be safely used in pharmaceutical applications. This can be attributed to its wide range of biological effects on higher organisms. Ricin is found exclusively in the endosperm of castor seeds and is classified as a type 2 ribosome-inactivating protein. Type 2 ribosome-inactivating proteins such as ricin from castor oil are lectins, which irreversibly inactivate ribosomes, thus stopping protein synthesis and eventually leading to cell death. This makes ricin a potent plant toxin (Houston et al; 2009).

MATERIALS AND METHODS

Sample Purification

The crude castor oil was purified through the following procedure; 200 ml of the castor oil was measured using measuring cylinder; the oil was pre-heated to 70ºC using hot magnet stirrer with thermometer. 1.5 ml citric acid was measured and added to the heated oil sample and continuously heated and stirred for 15 minutes at 70ºC. 4g of 8% KOH (by dissolving in 100 ml of distilled water) was then added to the oil and continuously heated and stirred for 15 minutes at 70ºC. The mixture was then transferred to the vacuum oven where it was heated at 85ºC for 30 minutes. Then the mixture was taken back to hot magnetic stirrer and heated to 70ºC after which a 2g of silicon reagent was added while it was being heated and stirred for 30 minutes. Then the temperature was increased to 85ºC and 4g of activated carbon was added to each 100 ml of the oil sample, heated and stirred for 30 munities. Then the mixture was separated using filter paper.

Trans-esterification

60g of the crude castor oil was measured in 250 ml of conical flask and was heated and stirred to a temperature of 60℃ - 65℃ on a hot magnetic stirrer plate, 0.6g of KOH was measured using the electronic weight machine and allowed to dissolve in 21 ml of methanol and then allowed to heat for 60 minutes with the stirrer on the hot magnetic plate. After 60 minutes of uniform stirring and heating on the hot magnetic plate maintaining a temperature of 65℃, it was then poured into the separating funnel through a glass funnel. The mixture was allowed to cool for about 40 min. However, it was observed that it separated into two liquid layers, the upper layer is biodiesel and low layer is triglycerol fatty acid.

Pour Point

Using an improvised method, the experimental procedures of pour point measurement for crude, purified and trans-esterified oils are enumerated below; the cylindrical test tube was filled with the crude castor oil to a specific level mark (5 ml). The test tube was clamped with a wooden clamp carrying the thermometer then placed in a bath of crushed ice (ice bath) and allowed to cool at a specified rate interval of 3 ºC for flow characteristics, the lowest temperature at which the movement of the oil is observed within 5 s is taken as pour point on the thermometer (ASTM 1999, D 97). The same procedure was repeated for the purified and trans-esterified castor oils.

Flash Point

The flash point for crude, purified and trans-esterified oils was also measured; A 100 ml conical flask was filled to a specific mark level (10 ml) with crude castor oil and heated at 14 to 17 ºC / min (25 to 30 ºF / min) on the hot plate until the temperature is 56 ºC (100 ºF) below the expected flash point, the rate of temperature changes was then reducing to 5 to 6 ºC /min (9 to 11 ºF/ min) and the test flame was applied for every 2 ºC (5 ºF) until the oil burn for at least 5s. The flash point was taken at the lowest temperature when an application of the flame test caused the vapor above the sample to ignite (ASTM 1999, D 92). The same procedure was repeated for the trans-esterified castor oils

RESULT AND DISCUTIONS

As reported by (Keera et al., 2018), viscosity is the internal fluid friction. In other words, viscosity is seen to be the resistance of oil to flow and it tends to oppose any dynamic change in the motion of fluid. One of the most important parameter that affect the yield of biodiesel is temperature, hence after conducting experiments of viscosity of crude, purified and trans-esterified castor oil at varying temperature and the result is presented in table 1 below.

Table 1 viscosity of crude, purified and trans-esterified oil.

Temp. (℃)	Viscosity of Crude Oil η (mpa.s)	Viscosity of Purified Oil η (mpa.s)	Viscosity of Trans-esterified Oil η (mpa.s)
25	68	60	52
30	64	52	50
40	53	50	43
50	50	47	40
60	47	43	37
70	44	41	34
80	41	39	31
90	38	35	30
100	35	30	28

The result obtained for viscosity is consistent with other reports presented by other researchers (Erhan, 1999). Castor oil is triglyceride like many other fatty acids that has about 10 % glycerin. It can be seen from the table that, trans-esterified castor oil has viscosities similar with the crude biodiesel oil for all the varying temperatures. This shows that viscosity is major reason why oils and fats are trans-esterified to biodiesel (Santos et al., 2011). Figure 1 below shows the Viscosity of Castor oil against Temperature.

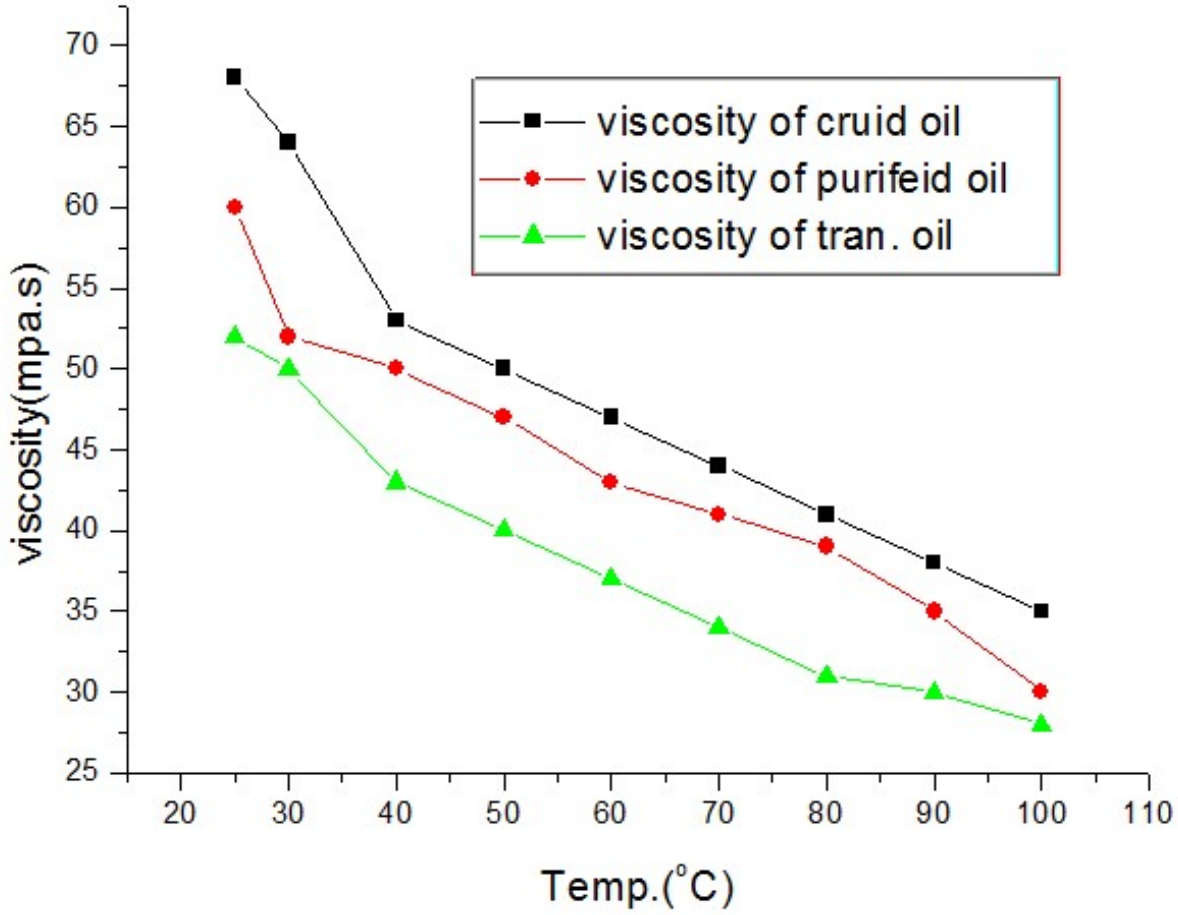

Figure 1. Graph of Viscosity of Castor oil against Temperature

Cooling equipment in industries is mainly governed by convection. So, it is necessary to have low viscosity for that application. In the Fig. 1, the result shows that as the temperature increases the viscosity is decreases. Also the viscosity of crude castor oil is greater than that of purified castor oil and viscosity of purified is greater than that of trans-esterified castor oil. Table 2 shows the Pour point, Flash Point and Fire Point Result of Castor.

Table 2. Pour point, Flash Point and Fire Point Result of Castor

Sample	Pour Point (°C)	Flash Point (°C)	Fire Point (°C)
Crude Castor Oil	12	120	133
Purified Castor Oil	9	123	145
Trans – esterified	6	130	152

Flash point and Fire point are important temperatures specified for safety during transport, storage and handling (Litchfield et al., 2006). The flash point and fire point of castor biodiesel was found to

be 130^{o}C and 152^{o}C respectively. Fuels with flash point 50 ^{o}C above 66^{o}C are considered to be safe fuel (Wang and Mujundar, 2007).

Flash point of castor oil increases after trans-esterification as shown in table 2; which shows that its volatile characteristics has improved and it is also safe to handle (Wang and Mujundar, 2007). The pour point of trans-esterified castor oil was +4^{o}C due to the high unsaturated fatty acid content in the oil. The result was found to be within the specified limit. But on the addition of 0.4% Al_2O_3 nano-particle, the Pour point of biodiesel increased to 6^{o}C after trans-esterification reaction.

CONCLUSION

Pure and Trans-esterified castor oil was prepared from the seeds of castor using Trans-esterification reaction methods, by using methanol and sodium hydroxide (NaOH) as catalysts to obtain biodiesel. The result indicated that pure, purified and trans-esterified castor oil have similar viscosities and the flash points indicated that castor oil can be used as biodiesel as the values are above 120 ^{o}C. Similarly, the flash points increases after trans-esterification which is an indication that the oil is safe to handle.

REFERENCES

Abitogun AS, Alademeyin OJ, Oloye DA. Extraction and characterization of castor seed oil. Internet J Nutr Wellness. 2009;8(2):1–8.

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, A. K., & Dhar, A. (2009). Performance, emission and combustion characteristics of castor oil blends in a direct injection CI engine (No. 2009-01-0947). SAE Technical Paper.

Agarwal, D., & Agarwal, A. K. (2007). Performance and emissions characteristics of castor oil (preheated and blends) in a direct injection compression ignition engine. Applied thermal engineering, 27(13), 2314-2323.

Akpan UG, Jimoh A, Mohammed AD. Extraction, characterization, and modification of castor seed oil. Leonardo Journal of Sciences. 2006; 8 :43–52.

B. P. Chandra and S. C. Bhaiya, A simple, accurate alternative to the minimum deviation method of determining the refractive index of liquids, Am. J. Phys. 51, 160–161 (Feb. 1983).

Babu, A. K., & Devaradjane, G. (2003). Vegetable oils and their derivatives as fuels for CI engines: an overview (No. 2003-01-0767). SAE Technical Paper.

Balat, M. (2006). Fuel characteristics and the use of biodiesel as a transportation fuel. Energy Sources, Part A, 28(9), 855-864.

Balat, M., & Balat, H. (2009). Recent trends in global production and utilization of bio-ethanol fuel. Applied energy, 86(11), 2273-2282.

Bhosle BM, Subramanian R. New approaches in deacidification of edible oils—a review. J Food Eng. 2005;69(4):481–494.

Boubel, R. W., Vallero, D., Fox, D. L., Turner, B., & Stern, A. C. (2013). Fundamentals of air pollution. Elsevier.

Bozbas, K. (2008). Biodiesel as an alternative motor fuel: Production and policies in the European Union. Renewable and sustainable energy reviews, 12(2), 542-552.

Cahoon EB, Kinney AJ. The production of vegetable oils with novel properties: using genomic tools to probe and manipulate plant fatty acid metabolism. Eur J Lipid Sci Technol. 2005;107(4):239–243.

Campbell SJ, Nakayama N, Unger EH. United Oilseed Products Ltd; 1 157 883. Chemical degumming of crude vegetable oils. 1983 Canadian Patent.

Canakci M, Van Germen J (1999) Biodiesel production via acid catalysis. Trans ASAE 1999, 42(5):1203–1210

Castor Oil Extraction, Castor Oil Refining Processes - CastorOil.in

Chakrabarti Mohammed H. and Rafiq Ahmed, Transesterification studies on castor oil as a first step towards its use in biodiesel production, Pak. J. Bot., 40(3), 1153-1157 (2008)

Chan AP, Crabtree J, Zhao Q, et al. Draft genome sequence of the oilseed species Ricinus communis. Nat Biotechnol. 2010; 28(9):951–956.

S.T. Keera , S.M. El Sabagh, A.R. Taman. Castor oil biodiesel production and optimization Egyptian Journal of Petroleum. 27 (2018) 979–984

S. Asadauskas, S. Erhan, Depression of pour points of vegetable oils by blending with diluents used for biodegradable lubricants, J. Am. Oil. Chem. Soc. 76 (1999) 313–316.

V.M.L. Dos Santos, J.A.B. da Silva, L. Stragevitch, R.L. Longo, Thermochemistry of biodiesel oxidation reactions: a DFT study, Fuel 90 (2011) 811–817