Production and Comparative Characterization of Castor Biodiesel as Alternative Fuel for Diesel Engines

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ABSTRACT

Biodiesel being as a clean, environment friendly, biodegradable fuel can deal with the crisis of fossil fuel depletion and environmental pollution. This paper represents the method of production of castor biodiesel by transesterification using methanol and NaOH. The factors that affect transesterification reaction such as alcohol content, temperature, reaction time, free fatty acid content were optimized. The fuel properties of castor biodiesel like kinematic viscosity, density, calorific value, flash and fire point, cloud and pour point were determined and compared with Indian standard biodiesel. It was concluded that after optimization of transesterification reaction, 130 ml of methanol and 2.5 g of NaOH were mixed with 500 ml of castor oil without heating for 1 h gives yield of 94.6% castor biodiesel. The calorific value of castor biodiesel was 4.84% lesser than that of diesel. The flash and fire point of castor biodiesel were higher than that of diesel. This paper revealed that the production of biodiesel from castor oil is a promising alternative fuel for diesel engines.

Keywords: Castor oil, biodiesel, transesterification, fuel properties, Indian standards

1. INTRODUCTION

In the recent years, world is facing the crisis of natural resources depletion and environmental degradation. As fossil fuel reserves are limited and continue to deplete to deal with energy demand increasing day by day. Biodiesel has become an attractive alternative fuel for diesel engine (Cao and Zhao, 2013). Biodiesel is a clean, biodegradable, renewable and promising source of fuel. Biodiesel can be easily blended with diesel in any proportion with no modification to the engine (Agarwal and Das, 2001). The transesterification reaction of castor oil were carried out at optimum conditions of reaction temperature of 59.89˚C, methanol to oil ratio of 8:10:1 and KOH catalyst of 1.22 wt% of oil. The methyl ester content under these optimum conditions was 94.5% w/w of oil and properties met the standards of EN14214 and ASTM D 6751. The viscosity and density of ester was reduced by blending with diesel upto B45 to satisfy within the ASTM 6751 and EN 14214 limits for castor biodiesel (Molla Asmare et al, 2014). The method of production of biodiesel from castor oil (treated with mineral turpentine oil) by transesterification with methanol in the presence of NaOH as catalyst to obtained conversion of 92% at 60˚C. (Babu et al., 2012)

1.1 Castor oil as biodiesel

Concept of using vegetable oils as fuel was introduced when Dr. Rudolf diesel developed first diesel engine to run on vegetable oil in 1885. His predictions come true and lots of countries are taking step towards alternative fuel for diesel engine (Babu et al., 2012). Nation is facing shortage of edible oil with increase in population demand, it would be viable to produce biodiesel from castor oil. Castor oil is non-edible oil which is yellowish in color extracted from castor bean (Shrirame et al., 2011). Castor oil consists of 80-90% ricinoleic acid (Table 1). The high viscosity of castor oil is mainly due to presence of ricinoleic acid (Achaya K, 1971).

Table 1. Composition of castor oil

Acid name	Composition (%)
Ricinoleic acid	85-90
Linoleic acid	4-5
Oleic acid	2-4
Stearic acid	1
Palmitic acid	1
Others	0.3-1%

The high viscosity of castor oil creates operational and durability problems in diesel engines if castor oil is directly run on the conventional diesel engine. High viscosity leads to poor atomization which in turn results in poor combustion, ring sticking, injector coking, injector deposits, injector pump failure & lubricating oil dilution. To improve the performance of diesel engine, viscosity has to be reduced. (M.C. Navindgi et al., 2012)

1.2 Need of Transesterification

The performance of castor oil in diesel engine can be improved by reducing viscosity of castor oil using transesterification. Transesterification is a reversible reaction in which castor oil reacts with a short chain alcohol and alkaline catalyst to form fatty acid methyl ester and glycerol as a product (Equation 1). Glycerol has low solubility in the oil so it gets settle down easily. Castor oil is filtered prior to use to remove impurities and also preheated prior to transesterification process. Alcohols that can be used in transesterification process are methanol, ethanol, propanol and butanol.

Methanol is mostly used because of its low cost, polar group, shortest chain alcohol. Basic as well as acidic catalysts are used in transesterification reaction. Basic catalyst are most preferable than acidic catalysts because of higher conversion rate and minimum reaction time. The basic catalysts that used in transesterification are KOH, NaOH, potassium methoxides etc. For base-catalyzed transesterification, factors that affects the reaction are alcohol content, temperature, reaction time, free fatty acid content, moisture content (J.M.Encinar et al., 2010).

O
‖
CH_2-O-C-R
| O CH_2-OH
| ‖ Catalyst |
CH_2-O-C-R + 3 R′OH ⟶ 3 R′-O-C-R + CH-OH
| O |
| ‖ CH_2-OH
CH_2-O-C-R

Triacylglyceride **Alcohol** **Alkyl ester** **Glycerol**

Equation 1. Transesterification reaction

2. MATERIALS AND METHOD

Figure 1. Transesterification setup

An experimental setup was used to perform transesterification reaction (Figure 1). Transesterification setup consists of a hot plate with magnetic stirrer and temperature regulator. The conical flask of 1000 ml covered with foil was placed over hot plate. The separating funnel is used to separate out the products such as crude biodiesel and glycerol.

2.1 Transesterification procedure

The transesterification process (Figure 2) was performed at laboratory of Thapar University, Patiala. Castor oil was filtered to remove gums and impurities. The transesterification method proposed by (Yung and Ping Lin, 2011) was optimized the factors to get higher ester recovery and low viscosity. Freshly prepare the mixture of 130 ml of methanol and 2.5 g of sodium hydroxide (NaOH) in the conical flask and stirred it until the flasks of NaOH dissolves in the methanol. At ambient temperature, add this mixture of methanol and NaOH into 500 ml of castor oil and quickly stirred it for 1 hour without heating. The products were allowed to settle overnight in the separating funnel. After that glycerol was removed from bottom of separating funnel. The crude biodiesel was washed with distilled water for about 3-4 times. After washing, crude biodiesel was stirred and heated at 110˚C to remove moisture traces and allow it for cooling at room temperature. The light yellow crystal clear biodiesel was produced and stored for usage.

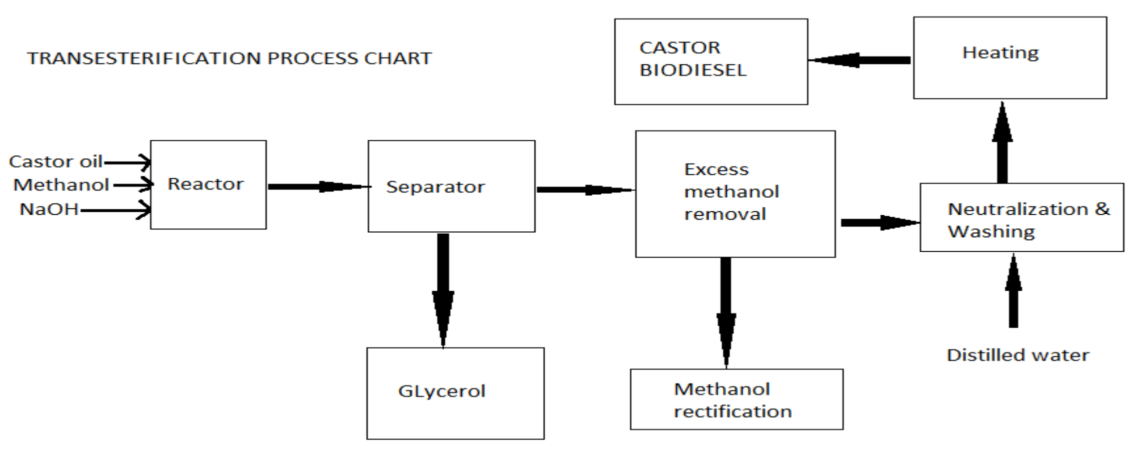

Figure 2. Transesterification process chart

2.2 Determination of fuel properties of castor biodiesel at MERADO, Ludhiana

After transesterification of castor oil, fuel properties of castor biodiesel were measured. The castor biodiesel properties were comparatively analyzed with diesel.

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2.2.1 Calorific value

It is quantity of heat liberated by completely burning of one unit mass of fuel. Bomb calorimeter was used to measure the calorific value of biodiesel and diesel. A fuel sample of 1 ml was burnt in the bomb calorimeter in the presence of pure oxygen. The sample was ignited electrically. As heat was produced, the rise in temperature was measured. The effective heat capacity was also determined using pure and dry benzoic acid as test fuel. (Van Gerpan et al., 2005)

2.2.2 Kinematic viscosity

It is measure of resistance to flow of a liquid due to internal friction of one part of a fluid moving over another. Redwood viscometer was used for determining the viscosity of oil expressed as a time of flow in seconds through specified hole over a metallic piece. Viscosity is measured in centistokes. Fuels having low viscosity may not provide sufficient lubrication for pumps and plunger results in leakage and abnormal wear. Fuels having high viscosity increase the pumping losses and reduce injection pressure results in poor atomization and insufficient mixing with air ultimately affects the combustion process. (Tate et al., 2006)

2.2.3 Density

It is mass per unit volume. It is calculated by weighing apparatus. Biodiesel was slightly heavier than conventional diesel fuel. This allows use of splash blending by adding biodiesel on the top of diesel for making blends of biodiesel. Biodiesel should be added at top of diesel fuel. If biodiesel was first put at the bottom and then diesel fuel was added, it would not mix. (Van Gerpan et al., 2005)

2.2.4 Flash and Fire point

It is a temperature at which it will ignite when exposed to a flame of light. Pensky–Martens flash and fire point apparatus was used to measure the flash and fire point of the biodiesel and diesel. Flash point can indicate the possible presence of highly volatile and flammable material in a non-volatile material. The fire point was an extension of flash point in a way that it reflects the condition at which vapour burns continuously for five seconds. The fire point was always higher than flash point by 5-8˚C. (Tate et al., 2006).

2.2.5 Cloud point

Cloud point is a temperature at which a haze of crystals appears in the fuel under test conditions. Pour point is a lowest temperature at which diesel will begin to flow. In the determination of the cloud point, sample was cooled under prescribed conditions and was inspected at intervals of 1˚C until a cloud or haze appears.

In determination of pour point, the sample cooled under prescribed conditions and inspected at intervals of 3˚C until it will no longer move when the place of surface was held vertical for 6 seconds, the pour point was then taken as 3˚C above the temperature of cessation of flow. It becomes important for low temperature operations. Both properties may indicate filter plugging and flow problems in the fuel line. (Van Gerpan et al., 2005)

3. RESULTS AND DISCUSSION

3.1 Optimization of transesterification results

The studies were conducted on optimizing the factors that affects the transesterification of castor proposed by Yung and Ping Lin, 2011. The ester recovery and viscosity was affected by the transesterification factors such catalyst quantity, reaction temperature, amount of methanol used (Table 2). The factors that affect the transesterification reaction were standardized to obtain castor biodiesel with lowest kinematic viscosity and highest level of ester recovery.

Table 2. Change in ester recovery and viscosity with respect to methanol quantity

Castor oil (ml)	NaOH Quantity (gm)	Methanol Quantity (ml)	Reaction time (hour)	Settling time (hour)	Ester recovery (gm)	Kinematic viscosity (cst)
500	2.5	110	1	24	95	8.14
500	2.5	130	1	24	94.6	7.37
500	2.5	150	1	24	71.3	6.93
500	2.5	160	1	24	68.7	6.46

It was observed that highest recovery of methyl ester of castor was obtained when 500 ml of castor oil was reacted with 110 ml of methanol and 2.5g of NaOH for 1 hour without heating and settled for 24 hours. After settling in the separating funnel, separate out the glycerol from biodiesel. The crude biodiesel was heated at 110˚C until it gets crystal cleared. Then biodiesel was allowed to cool down and store it for use. As ester recovery was higher at 110 ml of methanol, but at this percentage the value of viscosity was also higher. At methanol quantity of 130 ml, the ester recovery is slightly less but the viscosity was lie in the range (Table 3). Further addition of methanol was decreasing the ester recovery and also decreases the value of viscosity.

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Table 3. Optimized factors that affect the transesterification

Castor oil (ml)	NaOH Quantity (gm)	Methanol Quantity (ml)	Reaction time (hour)	Settling time (hours)	Ester content (gm)	Kinematic viscosity (cst)
500	2.5	130	1	24	94.6	7.37

3.2 Fuel properties analysis

The fuel properties were determined by various apparatus at (Cmeri, Ludhiana) (Table 4). The results of fuel properties were analyzed with the petrodiesel.

Table 4. Comparative properties of castor biodiesel and diesel

Properties	Method	Limit	Castor Biodiesel	DIESEL
Calorific value (KJ/Kg)	IS:1350	>33000	39967.19	42000
Density (Kg/cm^3)	ASTM D1298	-	900	830
Viscosity (cst)	IS:1448[P: 25] 1976	<5	7.37	3.04
Flash point (˚C)	IS:1448[P:32] 1992	>130	180	68
Fire point (˚C)	IS:1448[P:32] 1992	>53	185	73
Cloud point (˚C)	IS:1448[P:10] 1970	-3 to 12	2	-1
Pour point (˚C)	IS:1448[P:10] 1970	-15 to 10	- 3	-6

The overall studies based on production of castor biodiesel, fuel characterization of castor biodiesel and diesel were carried out. The following results were found out –

- The calorific value of castor biodiesel and diesel were found as 39967.19 KJ/kg, 42000 KJ/kg respectively. The calorific value of castor biodiesel is decreased by 4.84% than that of diesel.
- The kinematic viscosity of castor biodiesel and diesel were found as 7.37, 3.04 centistokes at 40˚C. The results indicated that the castor biodiesel has kinematic viscosity 58.7 percent more than that of diesel.
- The flash point and fire point of castor biodiesel was found to have higher than that of diesel.
- The cloud and pour point of castor biodiesel was found to have higher than those of diesel.

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- The density of castor biodiesel and diesel were found as 900 kg/cm^3 and 830 kg/cm^3 respectively. The results showed that the castor biodiesel has density more than that those of diesel

4. CONCLUSION

This study concluded that after optimization of transesterification reaction, mixture of 130 ml of methanol and 2.5 g of NaOH were react with 500 ml of castor oil without heating for 1 hour gives yield of 94.6% castor biodiesel. The calorific value of castor biodiesel was 4.84% less than that of diesel. The kinematic viscosity of castor biodiesel was 58.7% higher as compared to diesel. The flash point and fire point of castor biodiesel was higher than that of diesel. The castor biodiesel has more density than that of diesel. The cloud point and pour point of castor biodiesel was more as compared to those of diesel. The properties of castor biodiesel has meets the standards like ASTM, IS at some point except viscosity. The viscosity of castor biodiesel has slightly high above 5cst which was not within limit of Indian Standards. The viscosity further reduced by blending with diesel upto 30% to get within the Indian Standard Limit.

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REFERENCES

[1] Chun-yan Cao and Yong-hua Zhao, "Transesterification of castor oil to biodiesel using KOH/NaY as solid base catalyst", International Journal of Green Energy, Taylor & Francis, vol. 10: 219-229, 2013.

[2] Agarwal A.K. and L.M. Das, Biodiesel development and characteristics for use as a fuel in compression ignition engines, Journal of Engineering for Gas, Turbines and Power, vol. 123: 440-447, 2001.

[3] Molla Asmare, Nigus Gabbiye, "Synthesis and characterization of biodiesel from castor bean as alternative fuel for diesel engine", American Journal of Energy Engineering, vol. 2(1): 1-15, 2014.

[4] Penugonda Suresh Babu, Venkata Ramesh Mamilla, "Methanolysis of castor oil for production of biodiesel", International Journal of Advanced Engineering Technology, vol. 3: 146-148, 2012.

[5] Hemant Y.Shrirame, N.L.Panwar, B.R.Bamniya, "Biodiesel from castor oil – a green energy option", Scientific research, vol. 2: 1-6, 2011.

[6] Achaya K, "Chemical derivatives of castor oil", J Am Oil Chem Soc. 1971, vol. 48: 758-763.

[7] M.C.Navindgi, Maheswar Dutta, B. Sudheer Prem kumar, "Performance evaluation, emission characteristics and economic analysis of four non-edible straight vegetable oils on a single cylinder CI engine", ARPN Journal of Engineering & Applied Sciences, vol. 7: 2, 2012.

[8] J.M.Encinar, J.F.Gonalez, G.Martinez, N.Sanchez, C.G.Gonalez, "Synthesis and characterization of biodiesel from castor oil transesterification", International Conference on Renewable Energies and Power Quality, 2010.

[9] Yung-Sung Lin, Ha-Ping Lin, “Spray characteristics of emulsified castor biodiesel on engine emissions and deposit formation”, Renewable Energy, Elsevier, vol.36: 3507-3516, 2011.

[10] Tate, R.E., Watts, K.C., Allen, C.A.W. and Wilkie, K.I. “The viscosities of three biodiesel fuels at temperatures up to 300˚C”, Fuel, vol. 85: 1010-1015, 2006.

[11] Knothe, Van Gerpan and Krahl, “The Biodiesel Handbook”, National Centre of Agricultural Utilization Research Agricultural Research Service U.S. Department of Agricultural Peoria, Illinois, U.S.A, Department of Mechanical Engineering Iowa State University Ames, Iowa, U.S.A, University of Applied Sciences Coburg, Germany, 2005.

[12] Test report of characterization of castor biodiesel, www.cmeri.res.in, Central Mechanical Engineering Research Institute (MERADO), Ludhiana.