PERFORMANCE OF COMPRESSION IGNITION ENGINE WITH INDIGENOUS CASTOR OIL BIO DIESEL IN PAKISTAN

Mohammed Harun Chakrabarti[1] , Mehmood Ali[2]

ABSTRACT

Castor oil available indigenously in Pakistan was converted successfully to bio diesel and blended to 10% quantity (by volume) with high speed mineral diesel (HSD) fuel. This fuel was tested in a compression-ignition engine in order to assess its environmental emissions as well as engine performance parameters. The blended fuel was found to give lower environmental emissions in most accounts except for higher CO_2 and higher NO_X. In addition, three engine performance parameters were assessed, which were engine brake power, engine torque and exhaust temperature. In the first two cases, blended bio diesel fuel gave lower figures than pure mineral diesel due to lower calorific value. However, its higher flash point resulted in higher engine exhaust temperatures than pure mineral diesel. Overall, in terms of engine performance, castor oil bio diesel (from non-edible oil of castor bean – growing on marginal lands of Pakistan) fared better in comparison to canola oil bio diesel (from expensive edible oil) and can be recommended for further tests at higher blend ratios.

Keywords: Castor, compression-ignition, bio diesel, indigenous, non-edible.

1. INTRODUCTION

Pakistan, being an energy deficient country tends to import foreign petroleum fuel in order to sustain. This has lead to loss of revenue in addition to the non-harnessing of indigenous resources to meet the energy demands of an ever growing population. Petroleum fuel is well known to be present in limited supplies throughout the world and have thus been classified as non-renewable sources of energy. These fuels also tend to produce harmful emission products of combustion that cause major damage to the ecological environment [1]. Such alarming impacts are easily visible within the urban environments of Karachi. As a result, a new alternative is being sought in order to try and circumvent the damage caused by harmful pollutants into the environment. In this respect, bio diesel has emerged as an ideal candidate for gradually replacing mineral diesel fuel in the near future. Bio diesel has shown tremendous environmental benefits as an alternative fuel [2-6] and has thus been considered to be implemented slowly and steadily in this country. The government of Pakistan has passed a recent law that by the year 2015, at least 5-10% of bio diesel must be blended with mineral diesel fuel for use in the diesel run automobile industry. Various organizations in Pakistan have begun work in this regard but the literature lacks relevant results from their endeavors.

[1] Associate Professor, Department of Environmental Engineering, NED University of Engineering and Technology, Karachi – 75270, Pakistan. Ph. + 92-21-9261261-68 ext. 2225, Fax. + 92-21-9261255, Email: harun@neduet.edu.pk

[2] Assistant Professor, Department of Environmental Engineering, NED University of Engineering and Technology, Karachi – 75270, Pakistan. Ph. + 92-21-9261261-68 ext. 2271, Fax. + 92-21-9261255, Email: mehmood@neduet.edu.pk

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Mohammed Harun is an Associate Professor and Co-Chairman in the Department of Environmental Engineering at the NED University of Engineering and Technology, Karachi, Pakistan. He received his Bachelors and Masters in Chemical Enginering and Chemical Technology from Imperial College London in 1999. He received his PhD in Chemical and Environmental Engineering from Manchester University UK in 2003. He has published several articles on bio diesel.

Mehmood Ali is an Assistant Professor in the Department of Environmental Engineering at the NED University of Engineering and Technology, Karachi, Pakistan where he received his BEngg and MEngg in Mechanical and Environmental Enginering, respectively, in 1995 and 2002. He has supervised two independent study projects of Masters students on bio diesel production.

However, it is known that their work have focused on oils from the Jatropha plant and the pongame plant, as has been done repeatedly in India since the past decade [7-10]. Due to this issue, work has begun in earnest in the Department of Environmental Engineering, NED University to try and produce some useful results for the literature regarding the possibility of producing bio diesel from indigenous vegetable oils to try and meet the target set by the government of Pakistan [11]. Canola oil from indigenous sources has been converted successfully to bio diesel [11] and has also been tested in a compression-ignition engine in a separate work [12]. Results obtained were found to be consistent with the literature [13]. However, canola is an edible oil and cannot be grown easily on marginal lands of Pakistan. Hence, other oil varieties bearing non-edible qualities have been investigated in the literature, such as jatropha, pongame and castor [7-10, 14-16]. In this work, it was decided to investigate the possibility of converting indigenous castor oil to bio diesel [17] and then having it evaluated in a compression-ignition engine as a potential resource for the benefit of Pakistan. This was because the native castor bean plant has a greater ability to grow on marginal lands than the other non-edible oil yielding plants mentioned above [17].

2. EXPERIMENTAL TESTING

2.1 Composition of Castor Oil

The basic composition of any vegetable oil is triglyceride, which is the ester of three fatty acids and one glycerol. The fatty acid composition of indigenous castor oil was determined using the procedures outlined in the literature [18].

2.2 Bio Diesel Production

A two step ‘acid–base’ process, acid-pretreatment followed by main base-transesterification reaction, using methanol as reagent and H_2SO_4 and KOH as catalysts for acid and base reactions, respectively, was followed to produce bio diesel from refined castor oil in a laboratory scale processor [11, 17]. Indigenous canola oil was converted to bio diesel as per the procedure outlined in the literature [11].

2.3 Fuel properties

A series of tests were performed to characterize the properties of the produced bio diesel. These properties include density (ASTM D 1298), kinematic viscosity (ASTM D 445), cetane index (ASTM D 976, EN ISO 4264), flash point (ASTM D 93) as well as water and sediment contents (ASTM D 2709).

2.4 Engine emissions

The specifications of the compression-ignition engine (CIE) used in this work is described in **Table 1**. The fuel tested in the engine consisted of 100% High Speed Diesel (HSD) and 10% bio diesel with 90% diesel (B10), respectively. Emissions analysis from the diesel engine specified in **Table 1** was conducted at a constant speed of 2,600 rpm. The emission measurement system consisted of a self calibration exhaust gas analyzer (Testo Instruments Ltd.) and measurements were carried out in a similar manner to those of other workers [5]. The analyzer consisted of a number of probes including a temperature monitor. Parameters measured by means of the gas analyzer included carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_X), sulphur dioxide (SO_2) and particulate matter (PM). The engine was operated at 100% throttle and particulate matter was analyzed by means of a hand held device collecting exhaust particles on filter papers.

Table 1. Engine specification

Make	Rotronics
No. of Cylinders	2
Maximum Speed	2700 rpm (283 rad/s)
Bore	72 mm (2.83 in.)
Stroke	62 mm (2.44 in.)
Type	Four stroke, direct injection, air cooled
Injector opening pressure	12753 kPa (1849.2 lb/in^{2})
Displacement volume	505 cm^3 (30.82 in^3)
Oil Quantity	1.6 liters (0.057 ft^3)
Dry Weight	60 kg (132.3 lb)
Compression Ratio	8.5:1
Maximum output	2.0 kW (2.68 hp)
Nominal power	1.8 kW (2.41 hp)
Volume of cylinders	380 c.c. (23.2 in^3)

2.5 Engine performance

Engine performance was measured using 100% HSD and B10 only. This blend ratio was in line with the target imposed by the Government of Pakistan to blend up to 10% bio diesel with mineral diesel for the automobile sector by the year 2015. The performance of the engine was studied at different engine speeds following the procedures of other workers [6]. After the engine reached the stabilized working condition, gross brake power, engine torque applied and exhaust temperature were measured and analyzed [6].

3. RESULTS AND DISCUSSION

3.1 Fatty acid profile of castor oil

The fatty acid composition of indigenous castor oil was determined by means of gas chromatography as described in detail in the literature [17]. Results are reported in **Table 2**. The results obtained were very much consistent with those reported by other research workers [14, 15].

3.2 Fuel properties

The various fuel properties of castor oil, castor bio diesel (B100) and 100% high speed mineral diesel (HSD) as determined following the ASTM standards and procedures are summarized in **Table 3**. It can be seen from this table that the fuel properties of B100 are comparable with those of HSD and except for water content are well within the ASTM D 6751-02 and EN 14214 standards

Table 2. Fatty acid profile of castor oil

Fatty Acid	Values (wt. %)
Ricinoleic	90.2
Linoleic	4.4
Oleic	2.8
Estearic	0.9
Palmitic	0.7
Dihidroxiestearic	0.5
Licosanoic	0.3
Linolenic	0.2

Table 3. Fuel properties of castor oil, castor oil bio diesel and HSD

Parameters	High speed Diesel (HSD)	Castor Oil	Castor B100	Test Method
Density at 20 °C g/cm^3 (lb/in^3)	0.83 (0.027)	0.9584 (0.032)	0.9245 (0.031)	ASTM D 1298
Kinematic Viscosity mm^2/s (in^2/s)	2.73 (0.0042)	239.39 (0.371)	13.75 (0.0213)	ASTM D 445
Cetane Index	46	43	50	ASTM D 976
Flash Point °C (K)	37 (310)	310 (583)	120 (393)	ASTM D 93
Water and sediment vol. %	< 1	Nil	0.05	ASTM D 2709

for bio diesel [14, 17]. The castor oil and its bio diesel, however, was found to have much higher values of fuel properties, especially viscosity, way above any of these standard limits – thus restricting its direct use as a fuel for diesel engines. Similar conclusions were also discovered by other research workers [17].

3.3 Engine emissions

The high viscosity of the castor bio diesel limited maximum blend ratio to 10% only by volume (B10). The emissions of CO_2, CO, NO_X, and SO_2 against fuel type are shown in **Figs. 1 to 4**, With exception to the increases in carbon dioxide and oxides of nitrogen emissions with more bio diesel blended in the fuel mixtures, all other pollution parameters were found to decrease in general. Results were similar to those reported by other research workers [19]. In diesel engines without exhaust gas recirculation (EGR), the combustion of bio diesel almost always results in higher CO_2 in exhaust gases in comparison to diesel fuel combustion irregardless of fuel injection type used (**Fig. 1**). This is due to the presence of more carbon atoms as well as higher oxygen content in bio diesel fuel. In addition, bio diesel is more fuel-rich than diesel fuel thus resulting in higher combustion temperatures and high exhaust gas temperatures (**Fig. 5**). These reasons result in less oxygen content in exhaust gases obtained from the combustion of bio diesel fuel in comparison to mineral diesel fuel (**Fig. 6**).

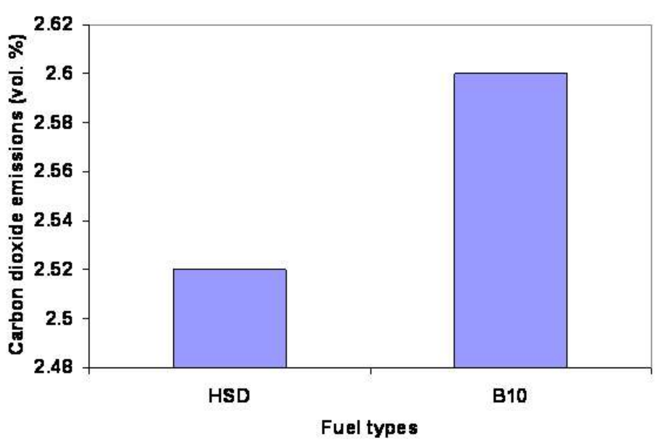

Figure 1. Carbon dioxide emissions from diesel engine operating on diesel fuel and castor B10.

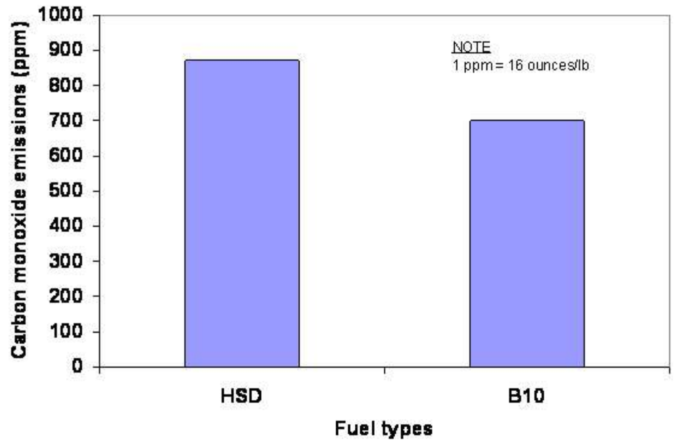

Figure 2. Carbon monoxide emissions from diesel engine operating on diesel fuel and castor B10.

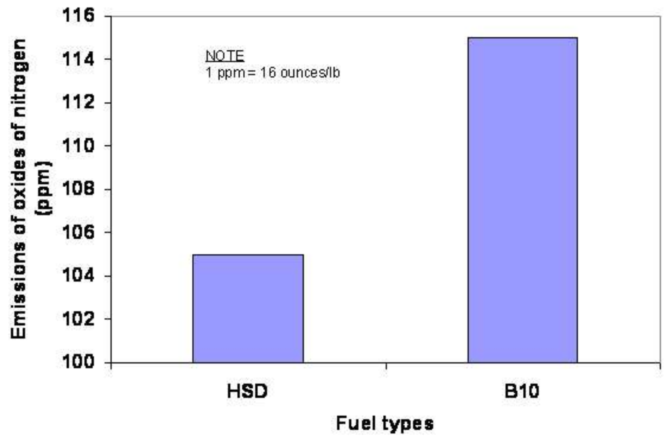

Figure 3. Emissions of Oxides of nitrogen from diesel engine operating on diesel fuel and castor B10.

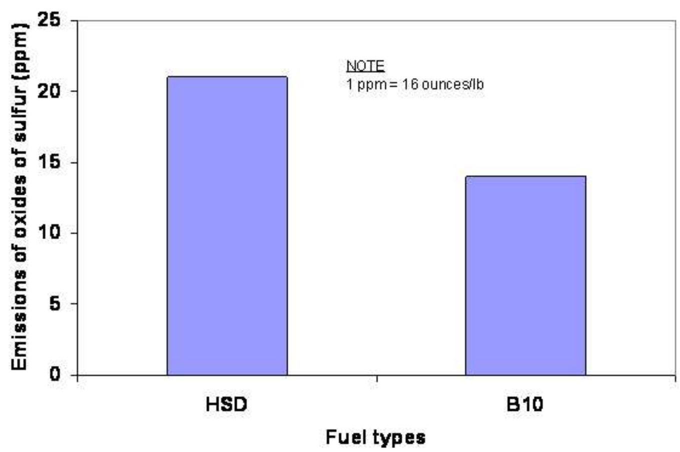

Figure 4. Emissions of sulphur dioxide from diesel engine operating on diesel fuel and castor B10.

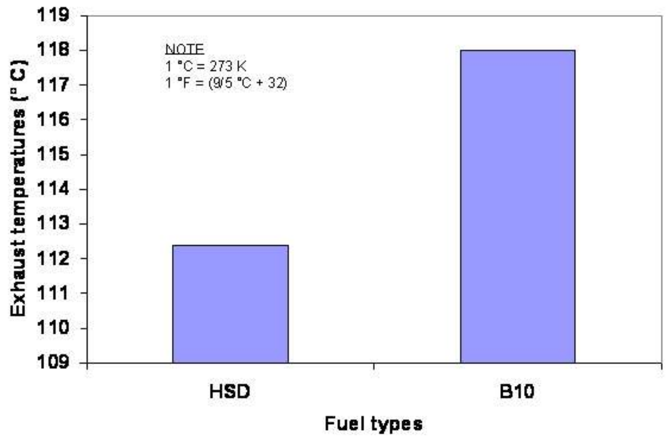

Figure 5. Exhaust temperatures of flue gases released by diesel engine operating on diesel fuel and castor B10.

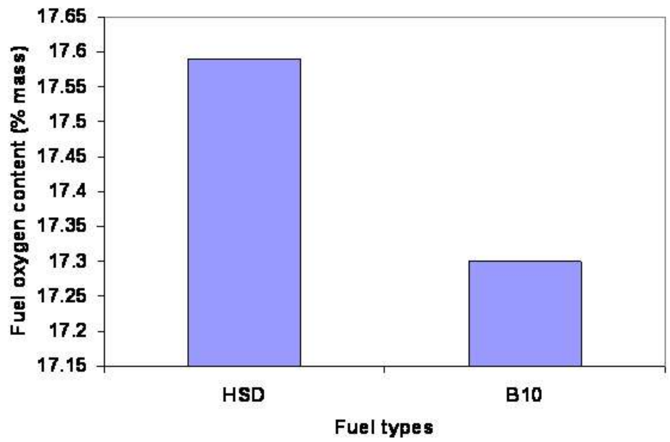

Figure 6. Fuel oxygen content in exhaust gases for diesel engine operating on diesel fuel and castor B10.

Particulate matter emissions from mineral diesel and blended bio diesel were also monitored. The results are displayed in **Fig. 7**. Particulate matter was found to decrease as expected when using castor B10 as engine fuel in comparison to mineral diesel fuel. Most of the results obtained are in full consistency with previous reported work conducted by other research workers [19].

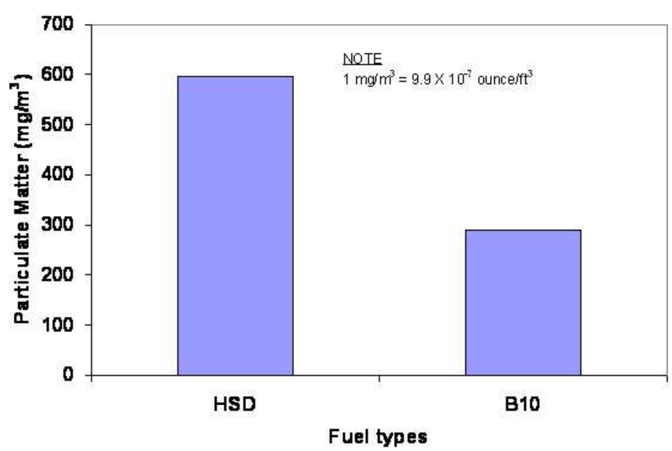

Figure 7. Particulate matter emissions from combustion of mineral diesel and blended bio diesel fuel in the compression ignition engine.

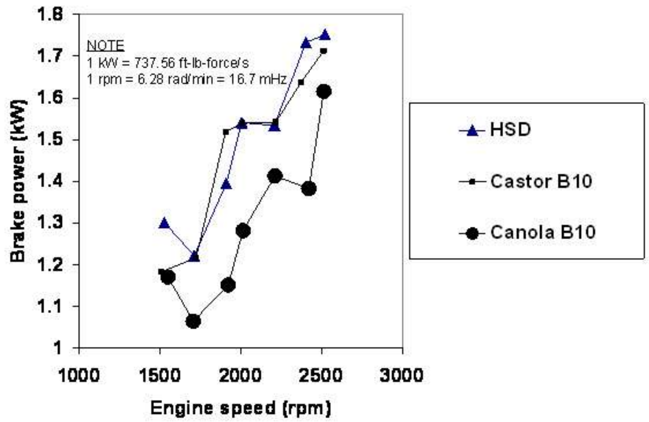

Figure 8. Variation of Engine Power against a range of engine speeds using three different fuel types (HSD; castor B10; and canola B10).

3.4 Engine performance

The engine performance of blends of castor oil bio diesel and mineral diesel (castor B10) was evaluated in terms of engine torque, engine exhaust temperature and engine brake power at different engine speeds of operation. Engine performance results of blends of canola oil bio diesel with high speed mineral diesel (canola B10) have been provided in this section for comparison purposes.

3.4.1 Brake Power

The variation of brake power for different engine speeds is highlighted in **Fig. 8**. Three different fuel types are depicted: HSD, castor B10 and canola B10. **Fig. 8** shows that there is slightly less power generated from blended bio diesel fuel as compared to mineral diesel fuel due to lower calorific value [11]. In addition, it was observed that blended castor bio diesel gave better engine power than blended canola bio diesel. The main reason for this is that the calorific value of castor bio diesel (38.7 MJ/kg) is higher than that of canola bio diesel (36 MJ/kg) [11].

3.4.2 Engine Torque

The variation of engine torque for different engine speeds is shown in **Fig. 9**. Three different fuel types are depicted: HSD, castor B10 and canola B10. The curves developed between mineral diesel and blended bio diesel showed that the petroleum diesel presented higher torque during engine testing. The reason for this was due to greater calorific value of mineral fuel in comparison to the bio diesel fuel. The graph pattern shows that initially more torque was required for operating the engine, but a gradual decline was observed with the passage of time (for all fuel types tested). Despite lower torque obtained, bio diesel still has some potential for employment in the compression-ignition engine and its performance can be improved as further research continues in this field.

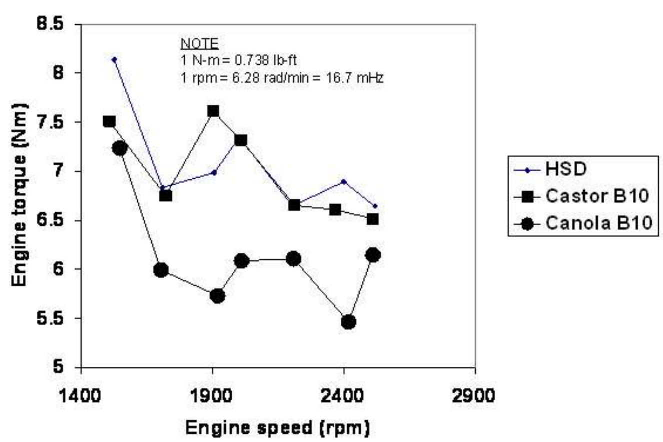

Figure 9. Variation of Engine Torque against a range of engine speeds using three different fuel types (HSD; castor B10; and canola B10).

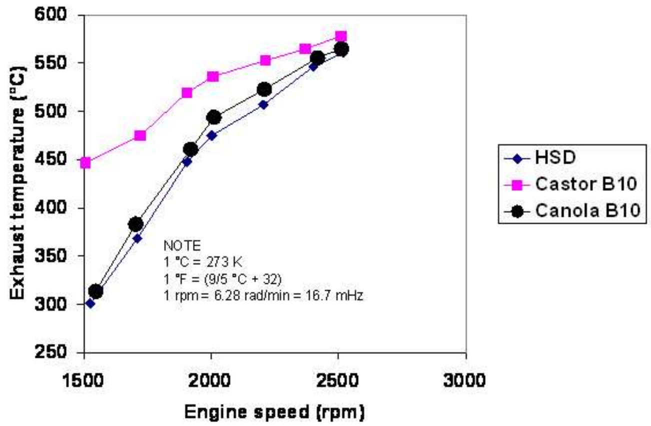

Figure 10. Engine Exhaust Temperatures against a range of engine speeds using three different fuel types (HSD; castor B10; and canola B10).

3.4.3 Engine exhaust temperature

Variation of exhaust gas temperatures against different engine speeds is illustrated in **Fig. 10**. Three different fuel types are depicted: HSD, castor B10 and canola B10. The exhaust gas temperature measurements showed that for mineral diesel fuel the temperature is less as compared to bio diesel blended fuel mixtures. This is basically due to a lower burning temperature developed in the combustion chamber when using mineral diesel as fuel. The burning of blended castor bio diesel was found to have the highest exhaust temperature as compared to blended canola bio diesel, due to its higher heating value and higher flash point [11, 17].

Bio diesel, having a higher oxygen content (as well as higher flash point) tends to burn at higher temperatures than mineral diesel fuel. In addition, the amount of injected fuel increases with the engine speed in order to maintain torque and power output [21]. Hence, the heat release rate and the exhaust temperatures from burning bio diesel rise with the increase in engine speed. One possible drawback of this is higher NO_X emissions, which may possibly be reduced by employing exhaust gas recirculation (EGR) technology as described in the literature [7].

4. CONCLUSIONS

Following conclusions may be drawn from the study reported in this paper.

1. Bio Diesel gives far less emissions than mineral diesel, except for carbon dioxide and NO_X. Higher CO_2 is released due to higher oxygen and carbon contents of bio diesel, thus signifying complete combustion of the fuel in compression-ignition engines. Higher NO_X releases are due to higher temperatures of combustion than mineral diesel fuel, but this could be reduced by employing catalytic converters or EGR.
2. The brake power and engine torque obtained with blended bio diesel fuel is less than that for mineral diesel fuel. This is mainly because of a lower calorific value of bio diesel in comparison to diesel.
3. Castor oil B10 gave higher brake power and engine torque in comparison to canola oil B10 (blended at 10% by volume).
4. Engine exhaust temperatures of blended bio diesel fuel mixtures are higher than that of pure mineral diesel, mainly due to the oxygenated nature of bio diesel.
5. Castor oil B10 gave higher exhaust temperatures than canola oil B10.
   Overall, castor oil bio diesel was found to give a better engine performance than canola oil bio diesel. This result is very positive because castor oil is not only non-edible but the castor bean plant can easily grow on marginal lands, thus making it a very valuable raw material for bio diesel production in Pakistan. However, before the castor oil can be recommended further, more work is necessary in trying to reduce its viscosity so that its bio diesel could meet the ASTM D 6751 standard limit [17]. If this could be achieved, higher blend ratios could be investigated in further work.

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