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Performance and Emission Characteristics of Thumba Oil Based Biodiesel on Diesel Engine: A Comprehensive Review

Shahid Qayoom* and Sumit Kanchan
School of Mechanical Engineering, Lovely Professional University, Phagwara – 144411, Punjab, India
✉ qayoomshahid@gmail.com

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Abstract: Nowadays, the whole world is facing the problems of lack of fossil fuels and the rise of emission level in automobiles like carbon dioxide, carbon monoxide etc. In order to prevent the whole world from these problems, a number of research developments are taking place to change the concept of using only fossil fuels by displaying some new alternative fuels to the market so that this dependence on fossil fuels can be reduced. For most of the countries in the world, there are limitations of petroleum-based fuels. In other words, the petroleum-based reserves are limited to certain countries. Therefore, those countries which are totally dependent on import of crude oil have to go through many crises or intense difficulties. Hence it becomes very important to develop some alternative fuels, which could be easily obtained from many available resources like vegetables etc.

Biodiesel is nowadays considered as the most effective, renewable and environmentally friendly fuel in place of diesel. While selecting the sources for extraction of biodiesel, the maximum focus is towards non-edible oils like Thumba, cotton, mahua oil etc., instead of edible oils like sunflower, palm, soybean oil etc., to reduce affecting food security. This review, therefore, displays various characteristics like performance and emission characteristics while using Thumba oil biodiesel in a diesel engine. Among highlights, this review covers properties of Thumba oil and Thumba oil treatment methods as well. In this review paper, researchers indicated that Thumba biodiesel reduces various pollutants like carbon monoxide (CO), hydrocarbon (HC), etc. related to diesel. It also covers that among all blends, preheated B20 Thumba biodiesel blend is having better emission and performance characteristics.

Key words: Thumba oil biodiesel, diesel engines, performance characteristics, emission.

Introduction

Conventional fossil fuels are reducing with time and it has been estimated that these fuels will vanish in next few years. With increasing emission level day by day due to these conventional fuels, it has become a dire need to develop some new alternative fuels to replace these non-renewable fossil fuels. From the economic and environmental point of view, biofuels are being considered as better alternative fuels to replace all non-renewable conventional fuels. For all alternative biofuels to be effective, it is important that they should be easy to renew and their availability should be higher and environmentally friendly. Among the alternative fuels, vegetable fuels like Karanja oil, cottonseed oil, neem oil, jatropha oil, palm oil, soybean oil etc. are being considered as the best promising alternatives relative to non- renewable fossil fuels. Even after developing these alternative fuels, there are some obstacles in making these fuels practically viable

*Corresponding Author

because of their limitations to high viscosity nature and less vaporization. Most research processes are going on to develop alternative fuels from vegetable oils because of having cetane number, heat energy, stoichiometric air/fuel ratio comparable to diesel fuel (Wang et al., 2006; Pramanik, 2003).

Biofuels as alternative fuels display better non-toxic, pollution reduction properties. Mainly dangerous pollutant emissions from automobiles like particulate matter, hydrocarbon, smoke, CO etc. are reduced to a large extent (Jain et al., 2017; Agarwal and Agarwal, 2007). It has been found that biodiesels oils have high oxygen content; lower ignition delay results in earlier combustion and hence produces higher cylinder pressures (Japurta et al., 2008). The main obstacles in using these biodiesels, which are extracted from vegetable oils, for long-term periods are higher engine deposition, sticking of piston rings, clogging of fuel injectors, increase in pour point of lubrication oil resulting in higher viscosity (Mofijur et al., 2013). Therefore, the main important parameter to make these alternative biodiesel fuels viable for Direct Injection Compression Ignition (DI CI) engines oils is to reduce their level of viscosity. Many researchers have developed many methods or techniques like blending of various vegetable oils with diesel, heating of oil before delivered to engine combustion chamber and transesterification (Sureshkumar et al., 2008; Hossain and Davies, 2010). Most researchers prefer to mix these oils with diesel to prepare environmental friendly and high efficient biodiesels. Among all alternative fuels, Thumba biodiesel can be a better choice for future automobiles.

Thumba Vegetable Oil

Thumba biodiesel (*Citrullus colocyntis*), generally referred as colocynth, belongs to a family of Cucurbitaceous (Herrari et al., 2015). This biodiesel is a non-edible vegetable oil, generally named as Indrayan in Hindi and Bitter Apple in English (Pal and Kachhwaha, 2011). This plant is being considered as a drought resistant type of species having a long deep root system, mostly found in many areas of Africa and Asia. In India, this type of plant is mainly grown in Rajasthan and Gujarat deserts. This plant also belongs to a Creeper plant species family and is largely found in sandy soil. It does not require any type of special care and its full growing cycle is 180 days approximately, which means it can be cultivated twice in a year. The qualities of this plant in comparison with diesel oil other than 'Jatropha' makes it more dominant (Pal and Kachhwaha, 2011). Nowadays, the oil of this plant is mainly used in soap industries (Karnwal et al., 2010). Hence due to its small crop cycle, it plays a very important role in the rural economy. Characteristics of Thumba oil are enlisted in Table 1 and pictorial representation is shown in Figure 1.

Table 1: Characteristics of Thumba plant (Dane et al., 2007)

S. No.	*Characteristics*	*Thumba plant*
1.	Fruit size	7-10 cm
2.	Seeds colour	Brownish
3.	No. of fruits/plant	15-30 circular shaped fruits
4.	Seeds size (approx.)	5-6 mm

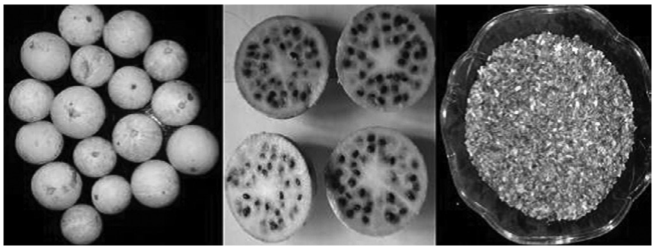

Figure 1: Thumba fruits and Thumba seeds (Karnwal et al., 2010).

Historical Background of Vegetable Oils

The development of considering vegetable biofuels as alternative fuels was at the top as the invention of a diesel engine was successfully done by Rudolf Diesel 1885 onwards. In 1912, it was mentioned that in due course of time, vegetable oils will become a main source of biofuel or biodiesel to propel vehicles and other machinery (Subramaniam et al., 2013). The eruption of Gulf crisis in 1973 encouraged large number of researchers to initiate research work related to vegetable oils. The usage of vegetable oils alone becomes insignificant due to many problems like low volatility and high viscosity. As a result Subramaniam et al. (2013), and Palanisamy and Manoharan (2005) suggested that following are the main advantages to use vegetable oils by mixing with diesel fuel:

- Biodiesel does not consist any toxic component.
- It consists higher oxygen concentration which in turn results in better combustion and better bio-degradation process.
- Enhances improvement in engine life because of having higher lubricating properties.
- The handling, transporting risks in case of biodiesel are lower because of having higher flash points.

Along with above advantages of biodiesels, Palanisamy and Manoharan et al. (2005) and Joshi and Pegg (2007) suggested disadvantages as well:

- Viscosity is higher.
- The viscosity increases further in low-temperature conditions, which in turn leads to blocking of filter cavities.

Kale and Rajit (2016) revealed that the Thumba oil is a best alternative source of fuel which can be used in diesel engines keeping in mind its best oil content (around 50%) based on its extraction. There were many research studies which have been performed to find out the comparison of performance and emission characteristics between Thumba biodiesel and diesel fuel. Hence, the main focus of this paper is to understand the performance and emission characteristics of diesel engines in which Thumba biodiesel is used as a fuel with different diesel oil concentrations by means of the literature review. The advantage of this plant is that it is having a low crop cycle (i.e., six months) and can be cultivated in sandy areas (Sharma et al., 2013).

Methods of Thumba Oil Treatment

In order to remove the above-discussed disadvantages like higher viscosity and low volatility, following methods were initially developed:

- Preheating
- Blending
- Pyrolysis (Thermal cracking)
- Transesterification

But many researchers have suggested that except transesterification, remaining methods are not economical. Hence, transesterification method is being considered as the most feasible or viable technique to extract the biodiesel from raw vegetable oils (Hossain and Davies, 2010) as discussed below.

Transesterification

Transesterification is a method which is mostly used for removing fatty acids or glycerol from Thumba oil by sharing the alkoxy group of an ester compound with alcohol along with a catalyst (acid or base) to vary the reaction time. In a transesterification process of Thumba oil, triglycerides (fat/oil) reacts with three molecules of alcohol (ethanol or methanol) to form esters (bio-diesel) and glycerol (Murugesan et al., 2012). Methanolysis and Ethanolysis in which methanol and ethanol are used as catalysts are shown in Figure 2 (Kanok et al., 2004).

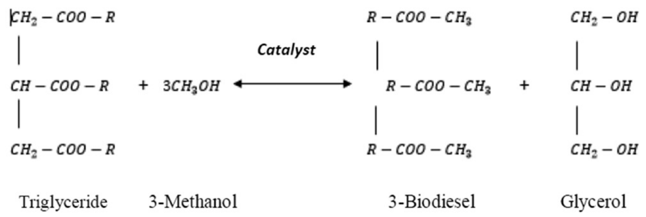

Figure 2: Transesterification reaction of biodiesel.

Thumba Oil Characteristics

Pramanik (2003) developed many methods to extract bio-diesel from vegetables. Among all methods, transesterification is being preferred as the best-optimized method. Before performing extraction methods, researchers mostly focussed on properties of biodiesel. Jain et al. (2017) and Nehdi et al. (2013) revealed the properties of diesel, Thumba oil (unheated) and Thumba oil (heated at 80-100 °C) as shown in Table 2.

Table 2: Comparison of properties of diesel and thumba oil (unheated and preheated)

Properties	*Thumba oil (Unheated)*	*Thumba oil (Heated @ 80-100°C)*	*Diesel*
Viscosity, cSt	32	6.5	4
Calorific value, MJ/kg	39.1	39.5	42
Flash point, °C	201	165	66
Fire point, °C	210	187	76
Pour point, °C	–5	–	-20
Cetane number	51	–	47
Fatty acid value, mg KOH/gm	3.14	–	0.24

Jain et al., 2017; Pramanik, 2003

From Table 2, researchers (Jain et al., 2017) reported that the viscosity of Thumba oil decreased after heating and becomes almost similar to diesel. The higher flash point and fire point of Thumba oil also make it possible to handle the biodiesel with less serious problems.

Results and Discussion

Impact of Thumba Biodiesel on Performance Characteristics of Engine

There are many research studies which reveals the variation of various engine performance parameters like Brake thermal efficiency (BTE), Brake specific fuel consumption (BSFC), Brake power etc. related to change in various operating and loading conditions at different biodiesel blending concentrations with pure diesel.

Brake Thermal Efficiency (BTE %)

BTE is an important parameter in engine performance which deals with the effective power developed in an engine by the application of fuel energy. To investigate the effect of Thumba oil for BTE of an engine, Jain et al. (2017) conducted an experiment by using a single cylinder four-stroke water cooled, 661 cc engine capacity with power and compression range as 3.5 kW and 12-22 respectively made by Kirloskar Ltd, and concluded that BTE varies for different blends of Thumba oil with diesel which is shown in Figure 3.

In this investigation, the researcher revealed that as the load increases, there is a gradual increase in BTE. The graph further reveals that BTE decreases as the concentration of Thumba oil increases. Among all blends, B20 is having BTE value almost nearer to diesel as shown in Figure 3. They explained that the lower BTE for higher blends of Thumba oil other than diesel is found due to the higher viscosity of thumba biodiesel which results in improper atomization and burning characteristics. Similarly, Kaushik et al. (2014) revealed in their experimental investigation that TME20 blend among all blends indicates BTE almost closer to diesel. Hence, these investigations conclude that in future machineries, Thumba biodiesel upto 20% blending percentage could be fruitful. Researchers (Khatri et al., 2010; Mishra et al., 2015) revealed in their results that as the load increased, all thumba biodiesel blends are following the same trend. This might be due to higher oxygen content and higher cetane number.

Brake Specific Fuel Consumption (BSFC)

Specific fuel consumption refers to the amount of fuel consumed to develop one unit of power in kilowatt per hour. It indicates the efficiency of obtaining power from fuel. To find out the impact of Thumba biodiesel for BSFC in an engine, Kumbhar and Dange (2014) performed an experiment on a single cylinder, four-stroke, variable compression ratio diesel engine with a volume of 661.45 cc. From the obtained results, it was revealed that under full loading conditions and at compression ratio of 17, B20 is showing BSFC with a slight reduction from BSFC of diesel fuel as shown in Figure 4. Researchers further observed that as the concentration of thumba biodiesel is increased like B50 and B100, BSFC starts increasing. This might be due to the lower calorific value and higher density of biodiesel. This investigation further signifies that B10 and B20 Thumba biodiesel blends are showing better performance as compared to diesel.

Researchers (Jain et al., 2017) in their observation also explained that among blends, B20 is having lower BSFC i.e. 0.33 kg/kWh and for B30, B10 blends, BSFC is 0.34 kg/kWh, 0.35 kg/kWh respectively. They also explained that there is 0.02 kg/kWh difference in BSFC between B20 preheated and B20 unheated Thumba oil. The main reason behind this conclusion might be an improvement in atomization of preheated B20 Thumba oil. Also, many authors (Jr. Erago et al., 2010; Karabektas et al., 2013) who studied different biodiesel blends suggested that the increase in BSFC by increasing biodiesel concentration is due to the fact that biodiesel has lower calorific value and lower energy density than diesel fuel.

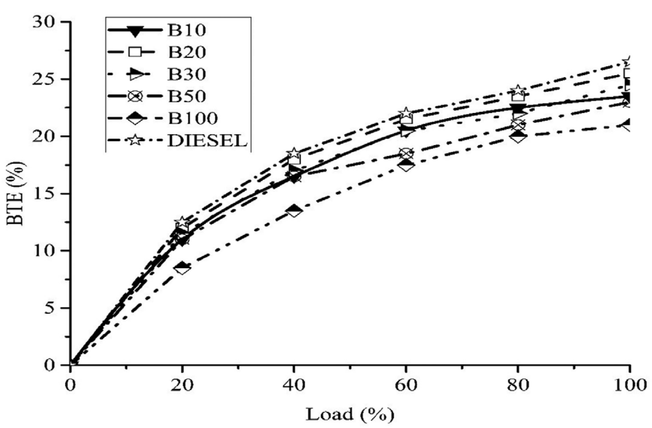

Figure 3: Effect on brake thermal efficiency using various Thumba biodiesel blends compared to diesel at various loads (Jain et al., 2017).

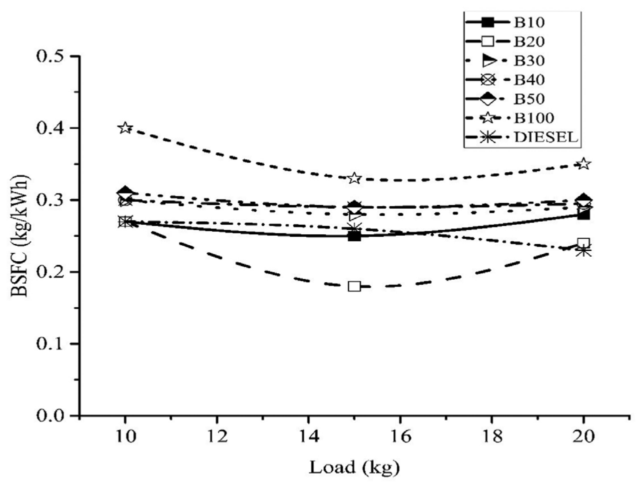

Figure 4: Effect on BSFC using various Thumba biodiesel blends compared to diesel at various loads (Kumbhar and Dange, 2014).

Brake Power

Brake power is referred as the rate of doing work. Bote and Dange (2014) revealed that for different blends of Thumba oil with diesel like B10, B20, B30, and B40, there is variation in brake power for different Thumba biodiesel concentration. In this investigation, researchers concluded that as the load increases, brake power also increases accordingly. They explained that as the load increases, demand for fuel increases because more power is required. Hence, as a result, more air and fuel enter which corresponds to increase in power.

Impact of Thumba Biodiesel on Emission Characteristics of Engine

During last many years, there is rapid growth in emissions from diesel engines due to the rise in population throughout the world. This rise in population increases the demand of diesel engine vehicles. Hence more focus was diverted to curb these emissions by adopting various stringent emission regulations in order to maintain the environmental safety. Nowadays biodiesel is being considered as the best alternative fuel for diesel engines due to availability and easier extraction technologies. Also, it is being mostly used because of its compatibility with the existing engine infrastructures. Therefore, biodiesel fuels are being referred as an important part of emission-reducing initiatives for internal combustion engines. Various research studies were performed in which it has been revealed that biodiesels play a very important role in reducing various critical pollutants from a diesel engine like carbon dioxide (CO_2), unburned hydrocarbons, PM etc. (Aldhaidhawi et al., 2017).

Carbon Monoxide Emissions (CO)

In compressed ignition engines, carbon monoxide is generated when an engine is being operated using highly rich fuel mixture and when the oxygen concentration is not in a proper amount to change all carbon into CO_2. Agarwal and Agarwal (2007) performed experiments using different Thumba biodiesel blends (B10, B20, B40, B60, B80, B100) in a single cylinder DI water cooled engine, and concluded that CO emission by using Thumba biodiesel is relatively small than conventional diesel fuel. They gave explanations that lower CO emission by using Thumba biodiesel is due to the presence of higher oxygen content which results in the better combustion process.

Sivakumar et al. (2015) conducted an experiment using various Thumba biodiesel blends (B20, B40, B60, B80, B100) and pure to investigate the effect on CO emissions as compared to diesel fuel on a single cylinder, 4-stroke water cooled, DI CI engine developed by Kirloskar Ltd having rated power output 5.2 kW at 1800 rpm with injection pressure of 210 bar. The investigation revealed that from 0 to 50% of loading condition, CO emission for B20 blend was showing the same trend related to CO emission for pure diesel. This investigation further revealed that under 75% of loading condition, B20 is indicating CO emission content lesser than diesel. This might be due to the higher oxygen content in biodiesel fuels. But as the loading parameter increases, CO emission for blends like B60 and B80 also starts increasing as shown in Figure 5. Similarly, Fontaras et al. (2009) revealed in their observation that for B50 and B100 blends, CO emission increases by 54% and 95% respectively related to diesel. They observed that increase in CO emission in this case using higher biodiesel blends is due to higher viscosity and poor atomization properties.

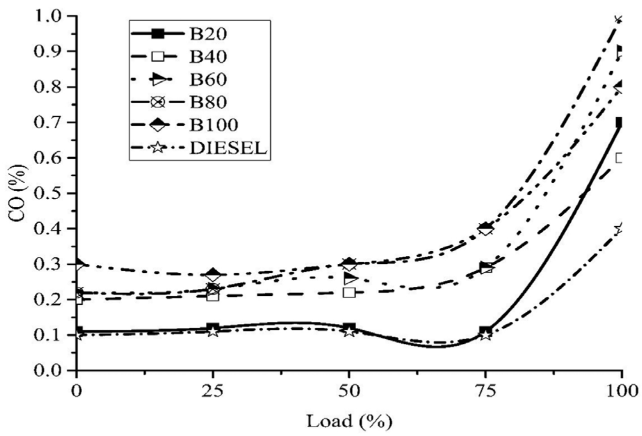

Figure 5: Effect of load on CO emission for different Thumba biodiesel blends compared with diesel (Sivakumar et al., 2015).

Carbon Dioxide Emissions (CO_2)

Carbon dioxide emissions are being referred as those emissions which originates due to complete combustion within an I.C. engine. Due to increase in the concentration of CO_2 in the atmosphere, it results in an abrupt increase in global warming (Alhaidhawi et al., 2017). Some researchers (Jain et al., 2017) revealed that the concentration of CO_2 increases linearly with increase in Thumba oil blend in diesel. They explained that the higher oxygen content in Thumba oil results in complete combustion process which leads to higher CO_2 emission.

To investigate the effect of thumba biodiesel on CO_2 emission in comparison with diesel, Jain et al. (2017)

conducted an experiment by using water cooled, single-cylinder diesel engine having total power output 3.5 Kw. They maintained the compression ratio between 12-22. During this study, researchers prepared some Thumba oil blends such as B10, B20, B30, B50 and B100. From Figure 6, it was found that up to 40% of engine load, almost all the blends are indicating higher CO_2 emission as compared to diesel. This might be due to the complete combustion of all the blends because of having higher oxygen which corresponds to efficient combustion (Song and Zhang, 2008; Usta et al., 2005). Beyond 40% of loading condition, diesel can be seen dominating in CO_2 emission as compared to other blends. They further revealed in their observation that B20 is having higher CO2 emission quantity in all blends and for blends B50 and B100, CO_2 emission decreases. This might be due to the increase in viscosity of Thumba oil resulting in incomplete combustion and hence low CO_2. From the results, authors also revealed that the CO_2 emission increases as the load increases.

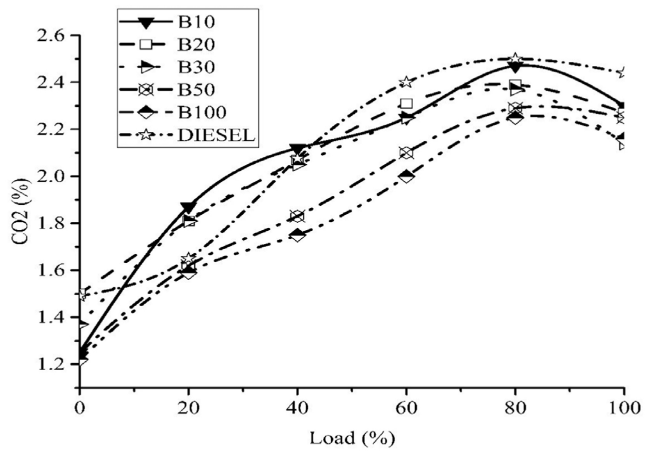

Figure 6: Effect of load on CO_2 emission for different Thumba biodiesel blends compared with diesel (Jain et al., 2017).

Nitrogen Oxide Emission (NO_X)

Researchers (Mathur et al., 2012; Kumbhar and Dange, 2014) concluded that as the concentration of Thumba oil blend in diesel increased, it was found that NO_X emission increases accordingly. This might be due to early combustion according to many researchers (Al-Widyan et al., 2002; Ozgunay et al., 2007). Nowadays, it has become a worldwide concern about the NO_X emission from using vegetable oils as biodiesel in engines. NO_X formation is generally influenced by (i) the quantity of fuel injected during delay period and (ii) the ignition delay time period (Pundir, 2011). The pilot injection plays a very important role in the reduction of NO_X. This type of injection is also referred as multiple-injection consisting two injecting pulses. The smaller time period for fuel injection during delay period helps in reduction of fuel burned during 'pre-mixed' combustion phase in a pilot injection process, which results in a reduction of delay period by injecting increased and faster amount of fuel during the main injection in a pilot injection process. This gives rise to shorter delay period, hence reduces NO_X by a reduction in combustion temperature (Osuka et al., 1994).

Researchers (Kumbhar and Dange, 2014) conducted an experiment to find out the effect of Thumba biodiesel on NO_X emissions in a direct injection compression engine as compared to diesel. Figure 7 compiles the whole results of this author in which it is clear that up to 15 kg of loading condition, B20 is displaying lower NO_X among all biodiesel blends as compared to diesel. Results from Figure 7 further signifies that as the concentration of thumba biodiesel is increased, NO_X emission also follows the same trend. Labeckas and Slavinskas (2006) revealed in their experiment that in case of biodiesels, oxygen content is higher which corresponds to increase in NO_X emissions. Hence thumba biodiesel up to 20% blending in diesel can be considered as best suitable biodiesel blend.

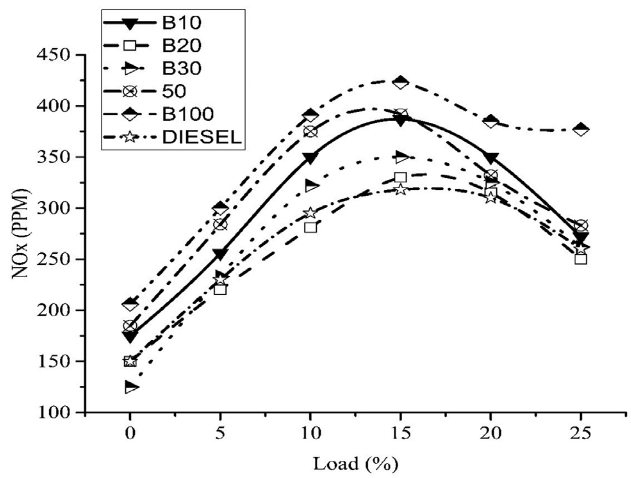

Figure 7: Effect of load on NO_x emission for different Thumba biodiesel blends compared with diesel (Kumbhar and Dange, 2014).

Hydrocarbon Emission (HC)

Hydrocarbon emissions are those emissions which are produced due to the incomplete combustion or due to change in fuel-air mixture ratio. The main reasons behind HC emission in a diesel engine are (Pundir, 2011):

1. Impingement of sprays on walls, crevices.
2. Overmixing of fuel with air.

To investigate the effect of Thumba biodiesel on HC emission in diesel engines, Gujar et al. (2015) conducted their research study using a single cylinder, 4-stroke diesel engine at 1500 rpm with a total power output of 5 HP. They prepared various Thumba biodiesel blends such as TB10, TB20, TB30 and TB00. The results revealed that hydrocarbon emission decreases in all blends of Thumba biodiesel related to diesel fuel.

Similarly, Jain et al. (2017) performed an experiment in which they concluded their results on comparing unheated B20 Thumba biodiesel, preheated B20 Thumba biodiesel and diesel as shown in Figure 8, from which it becomes clear that HC emissions from preheated B20 Thumba biodiesel (11 ppm) are lesser than unheated Thumba biodiesel (16 ppm) and diesel (20 ppm). Comparative performance and emission characteristics of Thumba biodiesel relative to conventional diesel fuel at different diesel engines are summarized in Table 3.

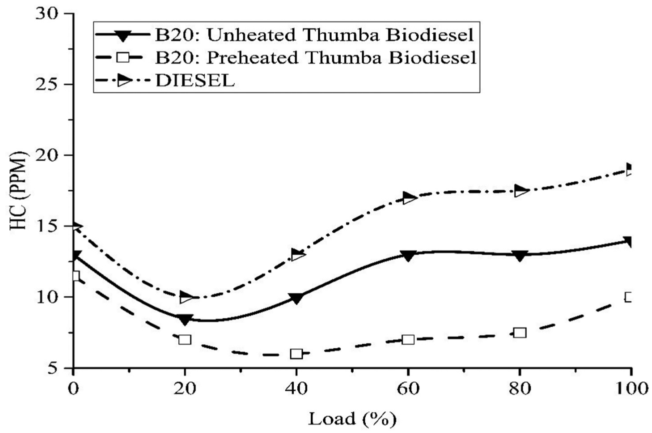

Figure 8: Effect of load on HC emission for different Thumba biodiesel blends compared with diesel (Jain et al., 2017).

Conclusions

Based on the extensive studies, following conclusions can be supported:

- The viscosity of unheated Thumba oil reduces due to its preheating at a temperature of 80-100°C. This preheating makes the possibility of reducing the viscosity of unheated Thumba oil from 32 cSt to 6.5 cSt similar to diesel's viscosity i.e. 4 cSt.
- Due to the higher flash point and fire point of Thumba oil, it is very easy to store and handle instead of diesel which has a lower flash point and fire point.
- With the increase in load, BTE increases accordingly. The main reason behind this might be due to lesser compressibility and higher cetane number of Thumba oil than diesel oil.
- Brake thermal efficiency decreases as the amount of Thumba oil in diesel blend increases. This is

Table 3: Comparative performance and emission characteristics of Thumba biodiesel relative to conventional diesel fuel in different diesel engines

Author	*Engine type*	*BTE*	*BSFC*	*CO*	*NO_x*	*HC*	*CO_2*
Jain et al., 2017	Single cylinder, 4-stroke water cooled, 661 cc, CI engine	Decrease	Increase	Decrease	Increase	Decrease	Slight decrease
Mishra et al., 2015	Single cylinder, 4-stroke, variable compression ratio diesel engine	Decrease	Increase	–	–	–	–
Pal et al., 2010	Four-cylinder, 4-stroke, water cooled, model Tata Indica diesel engine	Slight decrease	Increase	–	–	–	–
Gujar et al., 2015	Single cylinder, 4-stroke, diesel engine	Decrease	Increase	Decrease	–	Decrease	Decrease
Kaushak et al., 2014	Single cylinder variable compression ratio diesel engine	Decrease	Increase	–	Increase	–	–
Kumbhar and Dange, 2014	Single cylinder, 4-stroke, water-cooled diesel engine	Decrease	Increase	Decrease	Slight increase	Decrease	Slight increase

due to the fact that thumb a oil is having improper atomization due to a higher viscosity which in turn decreases burning characteristics.

- B20 blend is having better emission and performance characteristics.
- BSFC for all blends of Thumba and diesel decreases as the load is increased. The explanation for this change could be due to higher cetane number, lower compressibility, and lower ignition delay. But on the other hand, BSFC increases as Thumba oil concentration in diesel blend increases due to the lower vaporization and lower calorific value of Thumba oil than diesel oil.
- The quantity of carbon monoxide emission reduces by using Thumba biodiesel instead of conventional diesel fuel. The possible reason behind this is the higher oxygen content in Thumba oil which results in the efficient combustion process.
- Thumba biodiesel increases CO_2 emission with an increase in load but decreases CO_2 emission as the concentration of Thumba oil in diesel is increased. The higher level of CO_2 emission at higher loads might be due to proper mixing, atomization, and higher O_2 content, but on the other hand, the lower level of CO_2 emission at higher concentration of Thumba oil in diesel is due to higher viscosity results in incomplete combustion.
- The results also indicate that the CO_2 emission from unheated B20 Thumba blend is 0.3% lower than diesel.
- NO_x emission might be increased for using vegetable oils due to higher concentration of oxygen content but after blending with diesel, NO_x emission reduces might be due to shorter duration period of combustion, shorter delay period and higher CN as compared to diesel fuel.
- Appreciably by around 9 ppm of HC emission is lower in case of preheated B20 Thumba biodiesel as compared to diesel.

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