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AN INVESTIGATIVE STUDY ON ENGINE PERFORMANCE AND COMBUSTION PRODUCTS OF A MANUAL DIESEL ENGINE FUELED WITH AN OIL PRODUCED FROM LOCALLY AVAILABLE NAHAR SEEDS

ANIMESH DAS AND MANJULA DAS GHATAK*

Department of Mechanical Engineering, National Institute of Technology, Yupia, Arunachal Pradesh, India

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ABSTRACT

The trial results shows the change in various execution parameters and emission attributes of nahar oil biodiesel and its mixes with diesel in a four stroke four cylinder diesel engine and it is compared with the performance run by pure diesel. The outcomes from the tests demonstrate that nahar oil biodiesel and its mixes can possibly substitute for diesel engine in the ongoing future when non-renewable energy source stores become compromised. BTHE increases significantly with the increase of load whereas the value of thermal efficiency is almost same for the all blends with increment of the load. The power output and fuel consumption of engine is more or less same when engine is driven using nahar oil biodiesel mixes in comparison to diesel.

KEYWORDS : Transesterification, Biofuel, Emission, Engine performance.

INTRODUCTION

Today the whole nation feels paralyzed due to the energy crisis mainly the depletion of fossil fuels it faces. Most of the world's petroleum comes from the Middle East which is unstable politically. During the 1970s, due to unrest in those places resulted in reduced exports and India found themselves facing a fuel shortage for the first time since World War II (Demirbaº, 2002; Murugesan, *et al.*, 2009). Due to the increasing environmental pollution and some other issues the problems regarding shortage of fossil fuels has become acute which causing a record price hike of petrol and diesel in recent time which dictates that the changes are needed to take place as soon as possible (Banapurmath, *et al.*, 2012). Apart from price hike, the growing concern about environmental degradation and the consequence of greenhouse gases mainly because of emissions from internal combustion engine during the last two decades have received more interests of the researchers to find alternative sources and has motivated researchers to substitute fossil fuels with bio-oil from animal fats, vegetable oils etc (Randazzo and Sodré, 2011). Hence, it is high time to find out some alternative energy sources so that the energy crisis can be challenged globally discussed in (Sorate and Bhale, 2015). The advantages of using Vegetable oils are that they can be planted, bio-degradable, available worldwide, and low emission in burning (Çetin and Yüksel, 2007). The idea of using biodiesel produced from vegetable oil as an unconventional source of fuel for diesel engine is not new fangled. First vegetable oil (peanut oil) was used by Rudolph Diesel in 1900 at Paris Exposition (Zhu, *et al.*, 2011; Altin, *et al.*, 2001). After that many researchers have worked on different kind of vegetable oil, edible and non-edible both. But still the success to replace the conventional fuel in various applications is still an enigma. On the other hand, India produces only 30% of its requirement of aggregate petroleum fuels. The outstanding amount of fuel is imported mainly from Arabian countries which cost around Rs. 80,000 crore per year. Whereas just by mixing only 5% of bio-diesel with conventional petro-diesel about Rs. 4000 crores of

***Corresponding author's e-mail:** manjula.ghatak01@gmail.com

our country can be saved every year. Few easily obtainable alternative fuels are biodiesel, natural gases like CNG, LPG, alcohols like ethanol, methanol, butanol, hydrogen, fuel cells, biomasses and various types of vegetable oils as discussed in (Altin, *et al.,* 2001; Kasundra and Gohil, 2011; Santos and Capareda, 2015).

One of the major problems of using bio-fuel is that it has got very high viscosity (Dorado, *et al.,* 2003). Another problem is the higher cost of production of Biofuel (Wood, *et al.,* 2015; Williamson, *et al.,* 1998; Cig¯izog¢lu, *et al.,* 1997; Pramanik, 2003; Anggono, *et al.,* 2018). But the depletion of fossil fuel and increment of costs of it due to global crisis and govt. policies is basically the reason to look for alternative sources of energy. At the same time the harmful exhaust emission from diesel engines fueled with conventional diesel fuel is affecting the environment significantly which is definitely not acceptable for the future generation (Raheman, *et al.*, 2013). So to give a barrier to the continuous depletion of environment and produce green energy with an intention of clean environment for future gives a big motivation for use of biofuel as an alternative to fossil fuel for internal combustion engine (Atmanli, 2016).

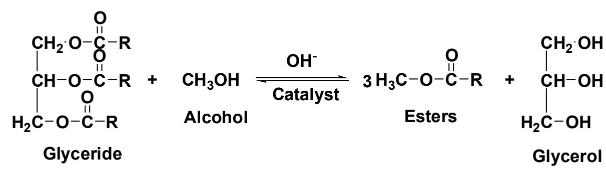
Though several experiments had been carried out to check the performance parameters of different types of vegetable oils, the experiments on nahar oil is yet in infant stage. Nahar oil is typical and different in nature because of its very high acid content and high viscosity which is very difficult to transesterify (Banapurmath, *et al.,* 2008; El-Kasaby and Nemit-Allah, 2013). In most of the literature (Rahman, et al., 2014; Sahoo and Das, 2009; Baiju, *et al.,* 2009), it is found that researchers have done base catalyst transesterification instead of acid catalyst transesterification which is not appropriate for all cases especially for nahar oil, because of its high acid value. **Dash and Lingfa, 2018** worked on nahar oil, but the methodology of transesterification is not described properly. The proper methodology of nahar oil transesterification is not clear from literature. Also, there is need of emission analysis for engine performance testing fueled with biodiesel of different blends.

In the present work, four-stroke Direct Injection Diesel (DID) engine is run consuming biodiesel prepared from nahar oil with no adjustment or modification in engine and its performance and emission analysis are carried out by varying load and various mixes of biodiesel. In this case blends of BD10, BD20, BD30 and BD40 are used at load variation of 10, 15, 17 and 20 kg respectively. Toward the end the outcomes are compared with that of conventional diesel as an alternative fuel for the four-stroke DID engine.

METHODOLOGY

Transesterification Reaction

Transesterification is the procedure in which alkoxy group of an ester is exchanged by another alcohol. In this process a glyceride reacts with an alcohol with the assistance of a catalyst developing fatty acid alkyl ester and an alcohol. These reactions are generally catalyzed in the presence of acid or base as shown in below (Das and Ghatak, 2018).



In base catalyzed transesterification oil from any vegetable or animal fat reacts with alcohol in the presence of base catalyst like NaOH/ KOH to produce biodiesel and a byproduct of glycerol as discussed in (Chuah, *et al.*, 2009). If the crude oil used had a high acid value, acid catalyzed can be used to transesterify fatty acids and produce bio-diesel. Transesterification has been used extensively in manufacturing industries like in soap and detergent industries globally for several years.

Most of the biodiesels are formed by transesterification using base or acid catalyst as it is the easiest and most cost-effective process at the same time requires low temperature. Also transesterification has almost 97% transformation return. The process of conversion of long chain hydrocarbon into small chains is called transesterification. In transesterification methyl ester is produced which is widely known as biodiesel and glycerol sediments at the bottom layer as a byproduct (How, *et al.,* 2019). As glycerol is heavier than methyl ester it settles down at bottom layer and may be used later on in industries like pharmaceutical, detergents, cosmetics etc. after purification. After the transesterification reaction the light weight biodiesel and heave weight glycerol makes two layers which need the separation and the crude biodiesel involves some stage of refinement prior usage.

Transesterification is the best method to make biodiesel from any vegetable oil or animal fat. Biodiesel is achieved by transesterification of triglycerides with alcohol within the sight of a catalyst. Catalysts are utilized to support the speed of response of reaction and to happen the reaction in a reasonable time as discussed in (Mohiddin, *et al.*, 2018). That catalyst may be base (for example NaOH, KOH) or acid catalyst (e.g. HCL, H2SO4) as per requirement. For this situation acid catalyst is used for transesterification because of the high acid value in nahar oil approximately 32mg KOH/g. Methanol is preferred as alcohol for its easy availability and also it is the cheapest one in market.

MATERIALS AND METHODS

Messua Ferrea L. is inborn to wet tropical regions of Sri Lanka. It is found mainly in Assam and Arunachal Pradesh and some other parts of India like above 1500 meter altitude of Eastern and Western Ghats in India. It is also found in other countries like Thailand, Malaysia, Nepal, Burma etc. Nahar oil is obtained by crushing the nahar seeds in a high-pressure mechanical oil crusher.

Fig. 1. Nahar Seeds and Kernels

The crude oil is filtered and the sediments are separated by filter paper. After filtration the esterification is performed on a three neck round bottom flask. A water cooled condenser is connected to one of the neck to reactor so that evaporative loss of methanol reduced. The reactor was placed on a magnetic stirrer and 500 ml of oil was poured in three neck glass, 250ml of methanol mixed with half the acid value (A V) of H_2SO_4 added to the oil in the reactor. Normally molar ratio vary from 3:1 to 12:1 the mixture was heated for 1-2 hrs at temperature range 60-80°C and 400 rpm on magnetic stirrer. After this product is kept in separating funnel where untreated methanol form a layer above esterifies oil, separating the oil, we sent it for further transesterification process. It is called double stage process of biodiesel production.

The reaction mixture was allowed to cool after completion of Transesterification. The mixture was transferred to separating funnel. Glycerol and biodiesel could be seen in two layers clearly. This phase separation took place clearly in 12-18 hrs of setting down. The biodiesel we obtained after Transesterification is crude biodiesel as it contains some amount of methanol and residual glycerol which cannot be used as biodiesel directly. Water wash of crude biodiesel is very important activity during biodiesel production, since presence of glycerol and residual methanol can be observed after the esterification reaction. These impurities were removed by washing with hot water. This process was continued till water layer became clear and transparent.

Then the ester is mixed with n-hexane in 1:1 ratio and stirred gently and then permitted to snuggle down for next 24h. This way the left over impurities of the mixture is detached with the help of a separating funnel. Then n-hexane was mixed with the remaining solution and the mixture was kept open for next 48 hours, so that with the vaporization of hexane some other impurities also vaporize and the pure nahar oil biodiesel is obtained. The NOME was then mixed properly with pure diesel oil in different proportion to prepare different blends, which afterwards involved in the performance tests of the engine. The different proportion of blends is indicated as BXX. Where 'B' stands for Biodiesel followed by numerical digits indicates the percentage of biodiesel contains in a particular blend (like the blend B10 contains 10% of biodiesel and 90% of pure diesel).

In this case we took petroleum diesel and four distinctive proportionate mixes of biodiesel with it which are BD10, BD20, BD30 and BD40 to exhibit the performance parameters of a four cylinder four stroke DID (Direct Injection Diesel) engine without any major modification. Some important properties of fuel like calorific value, flash point and fire point, dynamic viscosity, specific gravity etc. are already found out for all the taken blends (BD10, BD20, BD30 and BD40), pure biodiesel (BD100) and pure diesel before engine testing. The characterization of pre-defined blends of Nahar oil biodiesel with diesel is furnished thoroughly then their performances attributes and engine emission values are compared with neat diesel at a consistent engine speed (1500 rpm) on different pre-characterized load conditions like 0, 10, 15, 17 and 20 Kg load. The exhaust emission characteristics of carbon-mono-oxide (CO) and carbon-di-oxide (CO_2) was simultaneously observed for every condition.

Experimental Setup

The experiment was done in a four stroke four cylinder inline diesel engine from Tata Indica shown in Figure 2.

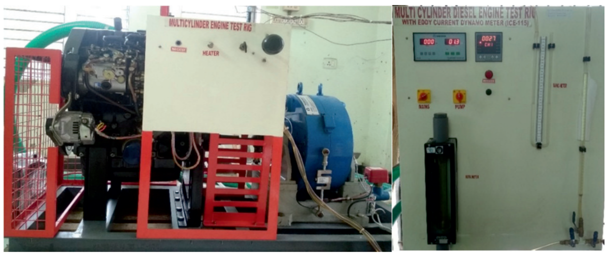


Fig. 2. Multi-cylinder test set-up.

The experimental set up consist of an eddy current dynamometer, a manometer and many sensors at different positions of inlet and exhaust which give temperature and pressure at different position. Also an exhaust emission analyzer is used to collect the CO and CO_2 emission data.

Before starting the engine it is ensured that there is sufficient water flow. The water flow to the cooling tank is kept at a level of 300 lph (liquid per hour) and the water flow to the calorimeter is kept at 70 lph. First water flow is sufficiently ensured so that the engine does not heat up during the course of its running. During the engine testing the compression ratio is maintained at 18 and other necessary specifications of test engine are mentioned in Table 1.

Table 1. Specification of engine.

No. of cylinder	Four
No. of stroke	Four
Fuel type	Diesel
Maker	TATA (Model: Indica)
Power of engine	10HP@1500 rpm
Stroke length	79mm
Bore diameter	75mm
Loading type	Eddy current Dynamometer (Length of Arm = 200mm)

RESULTS AND DISCUSSION

The test study was done to explore the performance and emission attributes of a direct injection diesel engine with Nahar oil methyl ester utilizing added substance and comparing it with that of diesel. The equipped biodiesel was characterized to decide its physical and substance properties like calorific value, flash and fire point, pour point, dynamic viscosity, specific gravity and compared with that of diesel. The CI engine was run under shifting load conditions, such as, 10, 15, 17 and 20 kgs individually to quantify the presentation parameters, for example, specific fuel consumption, brake thermal efficiency, brake power and furthermore to gauge the outflow parameters like carbon monoxide, carbon dioxide, oxide of nitrogen and unburnt hydrocarbon discharges for both diesel and the prepared nahar oil methyl ester with the assistance of exhaust gas analyser.

Before engine performance testing the major properties for the various mixes of nahar oil biodiesel with pure diesel (B10, B20, B30, B40 and pure biodiesel B100) are tried and the outcomes are shown in Table 2. The result shows that pure diesel has the most elevated CV and the least viscosity. As pure diesel blended to nahar oil biodiesel it is established that with the increase of the percentage level of FAME in different mixes the specific gravity is also increased but not significantly. The difference of the value of specific gravity of pure diesel to the pure nahar oil biodiesel is very little actually. However calorific value decreases sensitively with the expansion of level of percentage of NOME in the mixes. The pure nahar oil biodiesel has the most minimal calorific value and the highest specific gravity and pure diesel has the lowest specific gravity and most elevated calorific value.

The diesel engine ran and sounds well without any interruption in every blends of fuel referenced previously. No burdens were occurred during the entire process of experiment. The test outcomes are appeared in the accompanying tables and figures for different blends of biodiesel.

The engine was run with all the aforementioned blends and warmed up for few minutes for every case to warm up and reach in stabilized condition. When the engine reached the stabilized conditions various performance parameters like brake thermal efficiency, brake power, specific fuel consumption were measured in different load conditions as shown in Table 3. Different blends of methyl esters (B10, B20, B30 and B40) were taken as fuel to run the engine. From the view point of optimization, all the experiments are performed three times on the same setup and almost in same condition and took the average of all data observed.

Table 2. Properties of pure diesel and different blends of Nahar Oil.

Properties	Pure Diesel	B10	B20	B30	B40	B100
Specific Gravity (Kg/m^3)	0.838	0.8442	0.8504	0.8566	0.8628	0.9
Viscosity (cSt@40°C)	2.70	2.73	2.80	3.24	3.56	6.17
Calorific Value (KJ/kg)	43482	42540	41610	40670	39730	34105
Flash point (°C)	65	63	76	85	93	118
Fire Point (°C)	78	71	82	89	105	129
Pour Point (°C)	-8.7	-8.1	-7.3	-5.3	-3.5	5

Change in Brake thermal efficiency (BTHE) with Break power

BTHE is the measure of an engine how efficiently it transforms chemical energy of a fuel to thermal energy. Figure 3a shows the change in BTHE with load, and it is noticed that up to a certain load the efficiency directly correlates with load. The brake thermal efficiency of pure diesel contains highest value than that of the biodiesel blends for comparatively lower loads. The low temperature and higher viscosity of fuel during starting results in poor fuel spray which may cause low brake thermal efficiency. Then again oxygen content in bio-fuels are approximately between 35 to 40 percent only and that's why even if it is a very high oxygen content bio-fuel also, the energy density is almost half of the conventional fuel (Williamson and Badr, 1998). This low energy density due to low oxygen content also effects in the performance. However at higher range of loads the BTHE increases significantly for all the blend percentages than pure diesel.

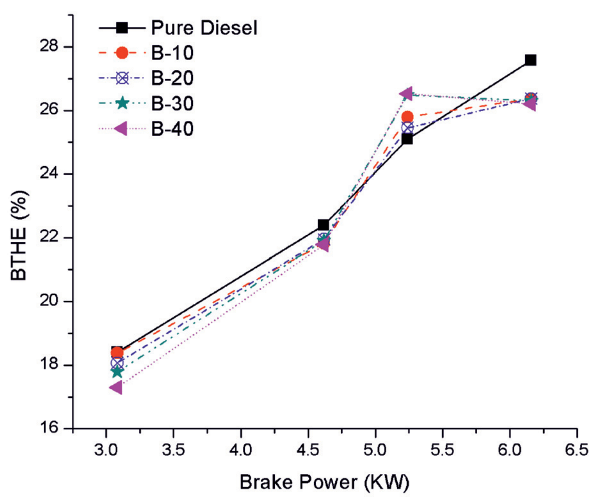


Fig. 3a. Change in Brake Thermal Efficiency with Brake Power.

Although the experiment is done three times for every blends of biofuel as well as for every load condition in almost same environment and in same setup, the average values are taken into consideration for plotting the graph. Hence an error bar is shown in Figure 3b for B30 only for simplification.

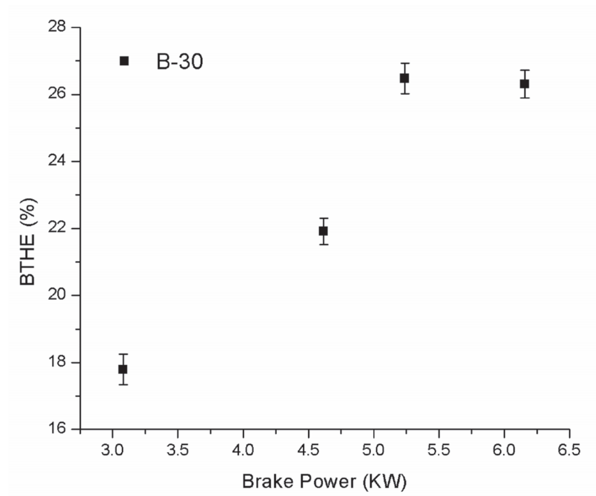


Fig. 3b. Change in Brake Thermal Efficiency with Brake Power

Among the other blends B10 is very much closer to the pure diesel in lower load and B40 deviates most and gives the lowest thermal efficiency. But with the increase of load thermal efficiency is almost same for the all blends. It is an encouraging note that with the increase of load better combustion of blends than lower load as compared to diesel.

Change in Brake-specific fuel consumption (BSFC) with break power

BSFC is a significant parameter to measure the engine performance which reveals how great an engine performs in terms of the amount of fuel consumed by it. This is generally expressed in Kg of fuel for every kilowatt-hour. Figure 4 displays the discrepancy in BSFC with loads for various mixes of NOME and it is noticed that specific fuel consumption of engine decreased with the increment of amount of engine loads. For various mixes of fuel the differences in BSFC are extremely less at various load conditions. The figure shows a general pattern of reduction in BSFC with increment of loads which is comparative in all the tried mixes of fuels. Among them despite pure diesel B10 shows lowest fuel consumption whereas B40 has the most than the other blends.

The lower viscosity and higher rate of increase of brake power than the rate of fuel consumption at the same time may be the reason behind this. Another reason may be that with the increase of combustion temperature, the transformation effectiveness of heat energy into mechanical expands which

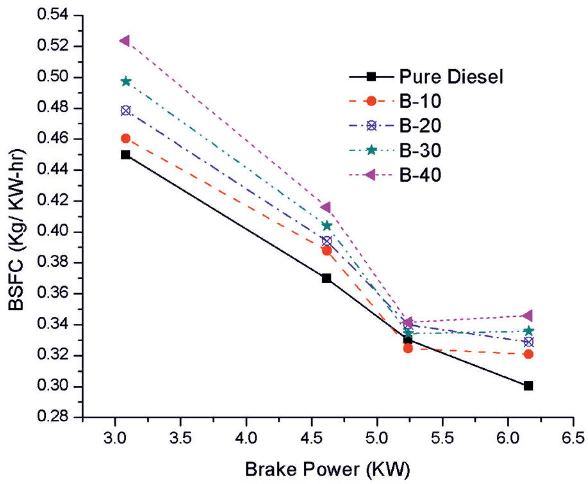


Fig. 4. Change in Brake Specific Fuel Consumption with Brake Power.

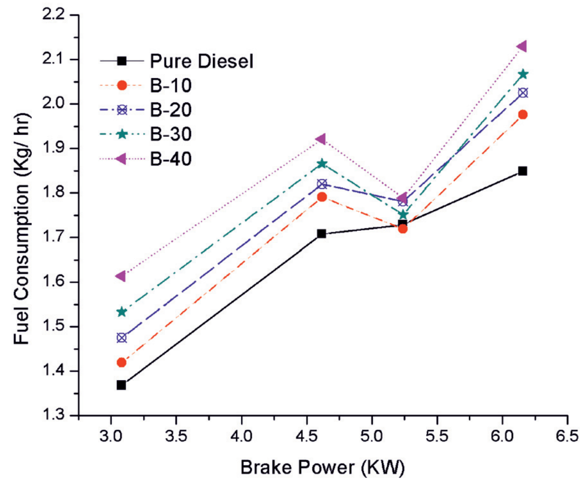


Fig. 5. Rate of change of Fuel Consumption with Brake Power.

Table 3. Engine performance result for pure diesel and its different blends.

Load (kg)	Blends	Fuel consumption Kg/hr	Brake power (KW)	Brake thermal efficiency (%)	Brake specific fuel consumption (Kg/KW-hr)
0	Diesel	0.809			
	B10	0.824			
	B20	0.833			
	B30	0.848			
	B40	0.855			
10	Diesel	1.386	3.082	18.41	0.4497
	B10	1.419		18.38	0.4604
	B20	1.475		18. 07	0.4785
	B30	1.533		17.79	0.4974
	B40	1.614		17.30	0.5236
15	Diesel	1.708	4.618	22.38	0.3698
	B10	1.791		21. 82	0.3878
	B20	1.820		21.95	0.3941
	B30	1.866		21.91	0.4040
	B40	1.921		21.78	0.4160
17	Diesel	1.729	5.239	25.09	0.3301
	B10	1.719		25.79	0.3247
	B20	1.781		25.45	0.3399
	B30	1.751		26.48	0.3342
	B40	1.789		26.53	0.3415
20	Diesel	1.849	6.158	27.57	0.3003
	B10	1.976		26.37	0.3209
	B20	2.025		26.37	0.3288
	B30	2.067		26.31	0.3357
	B40	2.130		26.20	0.3459

prompts decline in BSFC relating to engine loads.

Emission Analysis

Emission of CO happens because of deficient burning which causes incomplete combustion of hydrocarbons and improper air–fuel proportion. CO_2 is another byproduct of combustion which is basically made because of bonds out of carbon nearness in the fuel with oxygen in the air. Another explanation of creation of CO_2 might be because of high pressure and temperature in combustion chamber in which circumstances reaction of CO with oxygen presence (Mahanta *et al.,* 2008). Fig. 6 and 7 displays the difference of CO and CO_2 emission at various loads for different blends of biodiesel. At lesser load emission of CO is higher for all the blends than pure diesel but the same is found in decreasing order with the engine load increment. That may be due to the combustion delay, higher flash point for biodiesel blends and reduction in cylinder gas temperature at low load. At the same time Fig. 6 indicates though the amount of CO emission is higher for higher proportioned blends but the amount of emission decreases considerably with the increment of loads. This might be because of temperature rise in the combustion chamber due to higher load, gives mixing of air-fuel in proper ratio that results good ignition and better combustion of fuel.

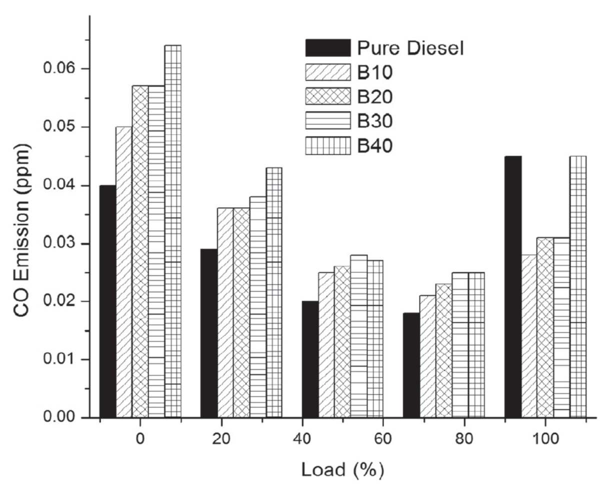


Fig. 6. Emission of CO for different blends of nahar oil biodiesel

The amount of CO_2 emits for different blends at different loads are shown in Fig. 7, which shows emission of CO_2 for all the blends in all loads is less than pure diesel. With the increment of percentage in of biodiesel in blends rate of CO_2 emission decreases for every load condition, which means carbon content in biodiesel is less than the petroleum fuel of same amount. With the increment of load amount CO_2 emission increases gradually as the amount of fuel spread into the cylinder also increases.

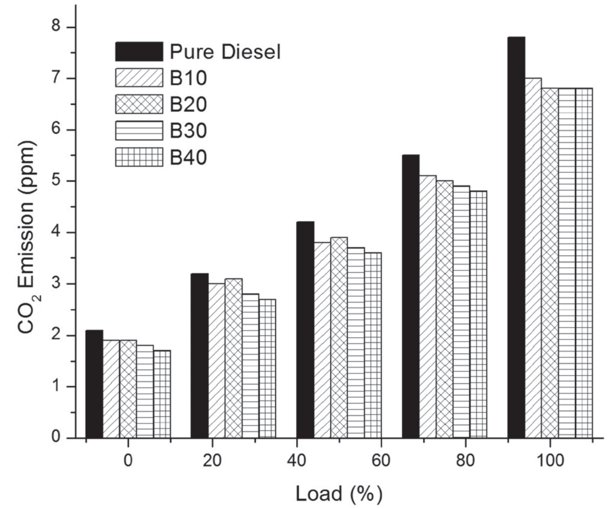


Fig. 7. Emission of CO_2 for different blends of nahar oil biodiesel.

Fig. 8 shows the amount of unburned hydro-carbon emits for all the blends of biodiesel in different load conditions. Emission of unburned hydro-carbon is less for all blends than pure diesel in lower loads but it increases with the increment of load. This occurs because in higher loads the amount of fuel sprayed into the cylinder is very high but the sufficient amount of oxygen may not be available in combustion chamber.

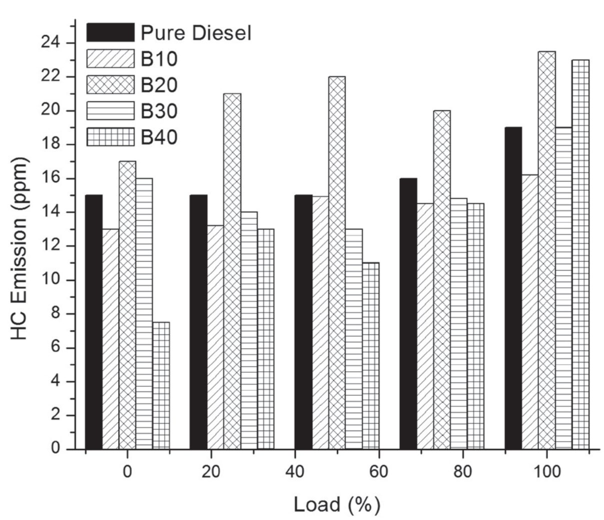


Fig. 8. Emission of HC for different blends of nahar oil biodiesel.

NO_x is the most harmful emission from any internal combustion engine, which is very dangerous for nature as well as for human health. The reason behind the NOx formation is the reaction between nitrogen and oxygen at a very high temperature and pressure. Fig. 9 shows the amount of NOx emission is significantly less for every blends of nahar oil bio-diesel in all loads, which indicates a very advantageous characteristics as an alternate to petroleum fuel. This is possible because of comparatively less temperature generation of bio-diesel and its blends than pure diesel especially during the combustion at higher loads. Which is possible due to the decrease in calorific value for higher proportioned biodiesel blends than petroleum diesel.

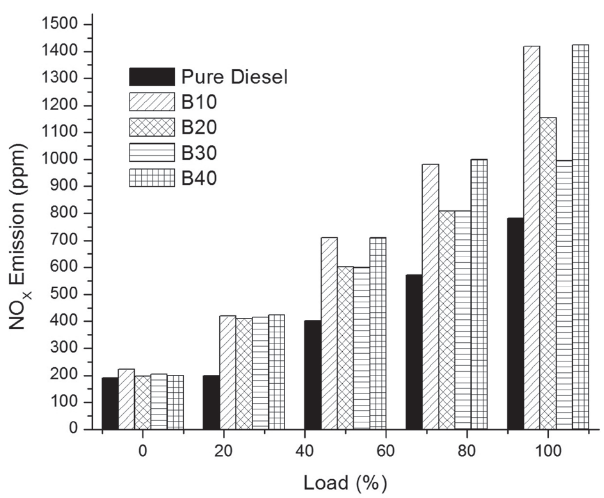


Fig. 9. Emission NO_X for different blends of nahar oil biodiesel.

CONCLUSION

The trial results shows the change in various execution parameters and emission attributes of nahar oil biodiesel and its mixes with diesel in a four stroke four cylinder diesel engine and it is compared with the performance run by pure diesel. The outcomes from the tests demonstrate that nahar oil biodiesel and its mixes can possibly substitute for diesel engine in the ongoing future when non-renewable energy source stores become compromised. BTHE increases significantly with the increase of load whereas the value of thermal efficiency is almost same for the all blends with increment of the load. The power output and fuel consumption of engine is more or less same when engine is driven using nahar oil biodiesel mixes in comparison to diesel. Though B10 shows lowest fuel consumption than the other blends, the values of BSFC are almost identical at various load condition, while utilizing different blends of fuels. Whereas B40 gives the significantly lower CO, CO_2 and most significantly NO_x emission for every variety of load. Subsequently, it very well may be presumed that the curiosity of the work lies in the development of an appropriate methodology of nahar oil transesterification, improvement in engine parameters and emission analysis through exhaust produced from diesel engine while working with various mixes (specifically higher blends) of NOME and conventional diesel. It also concludes that nahar oil biodiesel may be well-thought-out as a substitute of petroleum derivative mainly diesel for operation condition at standard load without major modification in engine.

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