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Article

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Research paper

Performance and emission characteristics of diesel engine fueled with rice bran biodiesel and n-butanol

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ABSTRACT

Due to the depletion of petroleum products and fatal emissions from the tailpipe of diesel engines it has become a need to seek for the alternative of petroleum products for long-term use. Currently, researchers and experts have come to the conclusion that biodiesel along with higher alcohols can be an appropriate substitute for this situation. Former investigations have presented that biodiesel and higher alcohol can help in improving the performance and depreciating harmful exhaust gases in a diesel engine. In the current investigation blends of diesel, rice bran biodiesel and n-butanol were prepared to check its effect on performance and emission characteristics of a diesel engine. Biodiesel was prepared by single stage alkaline transesterification process in this study and after that blends of diesel–biodiesel and diesel–biodiesel–n butanol were prepared as B10, B20, B10 nb10 and B20 nb20. Then these blends were tested in a single cylinder, small utility diesel engine with a rated power output of 3.73 kW to compare them with baseline diesel. Experimental investigation demonstrates that blends of rice bran biodiesel and n-butanol can be used as a fuel in a diesel engine without any change in the engine.

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1. Introduction

Diesel engines are one of the dominant prerequisites nowadays in so many sectors owing to the fact that it has better fuel economy, higher efficiency, more reliability, lower fuel cost, and long-lasting capacity. Tailpipe emissions from these engines are very badly affecting the mankind and habitat from so many decades. Moreover, due to the hike in automobiles on roads the fossil fuels are depleting at an alarming rate which may result in its permanent deterioration in few decades. To overcome this, diesel engine specialists, researchers, and combustion analysts are trying to find a substitute fuel which can upgrade the performance characteristics of the engine and cut down exhaust emissions (Mahalingam et al., 2018; Mahla et al., 2018a; Singh et al., 2018; Chauhan et al., 2011). Biofuels is the primary choice of the researchers amidst all alternative fuels due to its properties which help in producing fewer greenhouse gases and soot emissions. Furthermore, these are sustainable in nature and economical than conventional fuels (Singh et al., 2018). Researchers have done experimentation and simulation study on diesel engines by using biodiesel prepared from various vegetable and animal fat oils and found that amidst

reasonable, low grade and renewable vegetable oils Rice bran oil secures top position (Yuan et al., 2013; Chauhan et al., 2010a; Singh et al., 2012; Chauhan et al., 2010b; Sharma et al., 2013; Rai et al., 2013b; Goga et al., 2018; Chhabra et al., 2017). Bora and Saha (2015) explored the opportunity of using Rice bran biodiesel, Palm oil biodiesel and Pongamia oil biodiesel as pilot fuel for a biogas run dual fuel diesel engine and revealed that Rice bran methyl ester was best in performance among all biodiesel oils. Liquid fuel reinstatement was also found maximal for Rice bran biodiesel whereas there was a decrement in HC and CO emissions for Rice bran methyl esters. The emission study also stated that NO_x emission declined for Palm oil and Pongamia oil methyl esters. Kaimal and Vijayabalan (2015) performed an experimental investigation on a diesel engine using Rice bran oil biodiesel and plastic oil and concluded that brake specific energy consumption of Rice bran methyl esters is more than plastic whereas the thermal efficiency of the engine was on the lower side with Rice bran biodiesel and plastic oil as compared to that of diesel.

Diesel engine experts have proved that the inclusion of higher alcohol in fuel helps in developing its properties. n-butanol is a dominant priority of researchers as a fuel in diesel engine owing to its inferior viscosity, higher calorific value and finite moisture absorbing capacity (Bora and Saha, 2015; Kaimal and Vijayabalan, 2015; Ndaba et al., 2015). Rakopoulos et al. (2015) mixed various proportions of blends of biodiesel, cottonseed vegetable oil, n-butanol, and ethanol and tested the combustion and emission

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characteristics of a six-cylinder diesel engine with turbocharger. For the steady-state conditions it was observed that smoke decreased when biodiesel blends were used. When biodiesel was blended with vegetable oil NO_x increased, but it decreased with n-butanol and ethanol. Mahalingam et al. (2018) found the outcome of doping pentanol to mahua oil methyl esters on performance and emission characteristics of the engine. They concluded that by adding pentanol to biodiesel there was an increment in brake thermal efficiency of the engine whereas brake specific fuel consumption was less as compared to pure biodiesel. There was a decrement in exhaust emissions with pentanol addition. Nitrogen oxide, carbon monoxide, hydrocarbons, and smoke emissions were fewer considerably. Jindal et al. (2015) concluded that by addition of small quantity of n-butanol in diesel and waste cooking oil biodiesel blends brake specific fuel consumption enhanced, whilst carbon monoxide emissions were found to be decreased; hydrocarbon and nitrogen oxide emissions were detected to be on the higher side in comparison with neat diesel. Atmanli (2016) compared ternary blends of diesel and higher alcohols. They adopted propanol, n-butanol, and 1-pentanol as higher alcohols and came to a conclusion that with 20% propanol addition in diesel and waste oil biodiesel, increased brake specific fuel consumption can be achieved as compared to n-butanol and 1-pentanol addition. Hydrocarbon and nitrogen oxide emissions were on the lower side whereas carbon monoxide emissions were more for all blends of higher alcohols in comparison to diesel.

Blends of diesel and biodiesel have been tested by so many diesel engine expert, but the use of these blends for an extended period results in a dilemma concerning operation and endurance of the engine due to higher viscosity, lower energy content, higher pour point, lower volatility etc. of biodiesel (Murugesan et al., 2009; Sivalakshmi and Balusamy, 2011). To overcome this n-butanol is added to blends of diesel and biodiesel which can assist in utilizing these blends in diesel engines for a long-term without any hassle owing to properties of n-butanol like lower pour point, lower viscosity, higher miscibility, lower density, improved blending stability etc. (Agarwal, 2007; Sukjit et al., 2018). Yoshimoto and Onodera (2000) blended n-butanol with rapeseed oil and diesel to figure out the performance and emission characteristics of a diesel engine and wound up that by blending 29% of n-butanol in diesel and biodiesel there was not much change in BSEC of the engine whereas smoke opacity was on the lower side. When n-butanol was blended with neem oil and diesel a decline in graph of HC, CO, NO_x, soot, BTE, and BSEC was reported by the authors in comparison with baseline diesel, whereas compared to pure neem oil the performance characteristics were higher, trend of emission characteristics were similar as in comparison with conventional diesel (Sivalakshmi and Balusamy, 2011). Rakopoulos (2013) used cottonseed oil to blend with diesel and 20% n-butanol by volume and reported that the emission characteristics of blends incorporating diesel, biodiesel, and n-butanol were higher relative to fossil diesel. BSFC of the engine was decreased whereas BTE increased for the same. Verma and Sharma (2016) selected Safflower oil to blend with diesel and n-butanol. The authors noticed that BSFC of the engine was higher in comparison to neat diesel when diesel–n-butanol blends were used. It was also disclosed that when less than 50% biodiesel by volume was blended in diesel and n-butanol increased BTE was achieved relative to pure diesel. NO_x, CO, and CO₂ exhalations were increased, while HC emissions decreased with blends of safflower oil and n-butanol in relation with natural diesel.

The review of the literature has concentrated largely on performance and emission characteristics of diesel engines fueled with biodiesel and higher alcohol blends. It can be seen that methyl esters and n-butanol can increase the efficiency of the engine and can also help in reducing the harmful gases emitted from

Table 1
Properties of n-butanol.

Properties	n-butanol
Chemical formula	C ₄ H ₁₀ O
Research octane number	96
Cetane number	17–25
Low heating value (MJ/kg)	33.2
Latent heat of vaporization at 25 °C (kJ/kg)	626
Kinematic viscosity at 20 °C (mm ² /s)	2.63
Density (g/m ³)	0.81
Flash point (°C)	35
Auto ignition temperature (°C)	343
Oxygen (% by weight)	21.62
Boiling point (°C)	117

Table 2
Properties of fuels used.

Property	Diesel	B100	n-Butanol	ASTM standard
Density (kg m ⁻³)	835	868	810	900
Viscosity (cSt)	2.72	4.38	3.64	1.9–6
Calorific value (kJ kg ⁻¹)	43 400	39 488.5	33 000	>33 000
Cloud point (°C)	–8	1		–2 to 12
Pour point (°C)	–6	–2	–45	–15 to 10
Flash point (°C)	78	155	35	>130
FFA (%)		0.12		<2.5
Saponification number (SN)		202.5		
Iodine value (IV)		79.67		
Cetane number (CN)	50	55.32		

the exhaust. According to open literature, no study has yet been initiated by any researcher to find out the effect of n-butanol on a diesel engine fueled with Rice bran biodiesel. Hence, in the current experimentation, the effect of Rice bran methyl esters blended with n-butanol will be evaluated on a diesel engine.

2. Materials and methodology

2.1. Fuel properties and mixing

The oil derived from the tough outlying beige colored coating of rice is known as Rice bran oil. Non-edible grade Rice bran oil was purchased from the local market to prepare biodiesel. Transesterification process was used to produce biodiesel from Rice bran oil in the chemistry lab. Other chemicals like methanol (purity 98%), n-butanol (purity 99.8%), and potassium hydroxide (purity 97%) were bought from Joshi Chemicals, Punjab, India. n-butanol was added as higher alcohol while methanol and potassium hydroxide was used as alcohol and catalyst respectively for preparing biodiesel. Measured properties of n-butanol are shown in Table 1. In the present experimentation diesel and Rice bran oil biodiesel blends were prepared. The blended fuel comprises 10% and 20% of biodiesel by volume named as B10 and B20 respectively. Two blends of diesel, rice bran oil biodiesel and n-butanol containing 10% and 20% of n-butanol were also prepared titled as B10–nBu10 and B20–nBu20 respectively.

2.2. Transesterification and biodiesel production process

Single stage alkaline transesterification process was adopted for producing biodiesel from Rice bran oil. A solution comprising of 135 mL of methanol and 2.5 mL potassium hydroxide was blended with 500 ml rice bran oil at a molar ratio of 10:1 and heated for a period of 120 min at a temperature of 50 °C (Verma and Sharma, 2016). Various properties of Rice bran oil biodiesel and n-butanol are shown in Table 2 which presents that according to biodiesel standard ASTM D6751 all the fuels are in reach of the particularized check.

Table 3
Engine specification.

Parameter	Description
Manufacture	Kirloskar
Engine type	Vertical, 4-stroke
Rated power output (kW)	3.75
Engine cooling	Air cooled
Engine speed (rpm)	1500
No. of cylinder	1
Stroke length, (mm)	110
Bore (mm)	87.5
Compression ratio	16.5:1
Displacement volume (cc)	252.9
Injection pressure (kg cm ⁻²)	200

Table 4
Uncertainty, range and accuracy of gas analyzer and smoke meter.

Exhaust emissions	Range	Accuracy	Uncertainties
HC	0–19,999 ppm	± 10 ppm	± 0.1 (%)
CO	0–4000 ppm	0.015%	± 0.4 (%)
Smoke		0.005%	± 1.0 (%)
NOx	0–4000 ppm	± 10 ppm	± 0.2 (%)

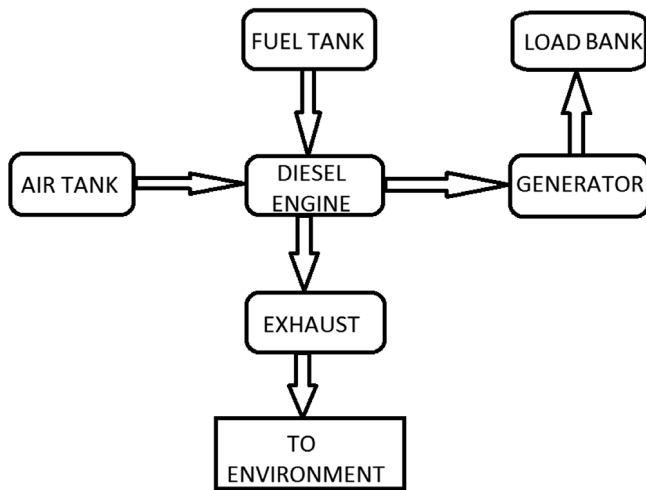


Fig. 1. Schematic diagram of experimental set up.

3. Experimental set up

A single cylinder, small utility diesel engine with a rated power output of 3.73 kW was employed in this study. It was direct injection; air-cooled engine manufactured by Kirloskar Oil India Ltd. Experimentation was done at a constant speed of 1550 rpm. Technical specification of the experimental test set up is illustrated in Table 3.

The power output of the engine was measured by an eddy current dynamometer coupled with the engine shaft and loaded with help of resistive load bank. An AVL DIGAS 444 N gas analyzer was used to measure the concentration of gaseous emissions such as unburned hydrocarbon, carbon monoxide, carbon dioxide, and nitrogen oxides. Digital readings of all the gaseous emissions were obtained by placing the probe in the exhaust of cylinder. A smoke meter was used to measure the smoke opacity. Accuracy and range of gas analyzer and smoke meter are shown in Table 4. Schematic of the engine set up is shown in Fig. 1.

4. Uncertainty analysis

Uncertainty is used to calculate any miscue of a conclusion. The authenticity of the experimental study may be affected due

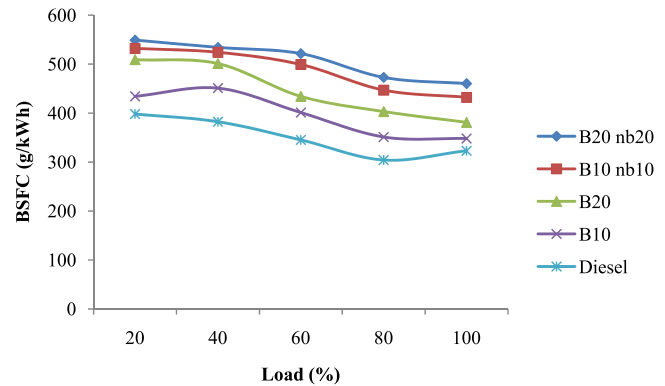


Fig. 2. Variation of BSFC with load.

to some uncertainties. To make sure that the obtained results are accurate uncertainty analysis must be performed. Calibration of all the apparatus used for experimentation is also necessary for getting the exact value. Most of the familiar investigators advise performing this analysis. Accordingly, to achieve a valid value all the experimentation was performed in a way that readings were taken more than two times and after that arithmetic mean of the entire range of values was calculated.

5. Result and discussion

The performance and emission parameters of the diesel engine energized with rice bran methyl esters and n-butanol are discussed in this segment. Whole experimentation was repeated for three times and mean value was taken to assure the certainty of the result.

5.1. Performance characteristics

5.1.1. Effect on brake specific fuel consumption

Brake Specific fuel consumption is a crucial criterion, to examine the efficiency with which the fuel is being consumed in an engine (Singh et al., 2018). Fig. 2 shows variations of BSFC when the engine was fueled with Rice bran methyl esters and n-butanol compared to baseline diesel. It was observed that with increment in load utilization of fuel decreased for all test fuels. It may be owing to the fact that at part loads the temperature of the cylinder is inferior as compared to high engine loads which bring about partial combustion of fuel and consequently contributes to higher BSFC. When combustion of fuel is not complete, it results in an excess amount of fuel required to get the same amount of energy and hence results in higher BSFC. Maximum BSFC was noted for B20 nb20 fuel blend at 20% engine load and minimum BSFC was recorded for pure diesel at 80% engine load. As the quantity of Rice bran biodiesel was increased in fuel blend BSFC was also on the higher side which can be owing to more viscosity, low calorific value and the high index of hydrogen deficiency of biodiesel (Verma et al., 2015). Lower energy content and higher viscosity of fuel leads to partial combustion and hence results in improved BSFC. BSFC also found to be increased with increase in the amount of n-butanol in fuel blends. It is correlated with the fact that the calorific value of n-butanol is less than that of baseline diesel and n-butanol ignites with lesser efficiency as compared to diesel (Satsangi and Tiwari, 2018; Dogan, 2011; Rakopoulos et al., 2010). Lesser efficiency of ignition of fuel leads to partial combustion of fuel and consequently higher BSFC.

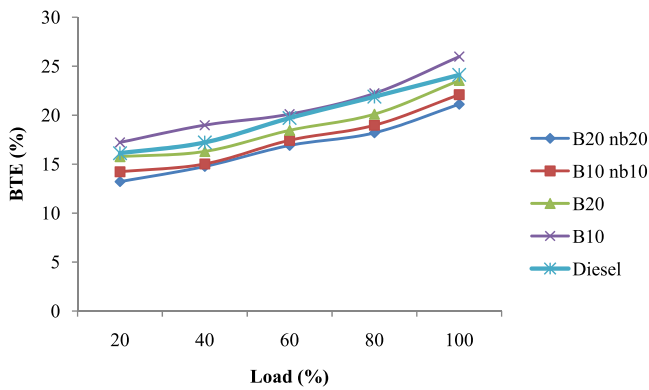


Fig. 3. Variation of BTE with load.

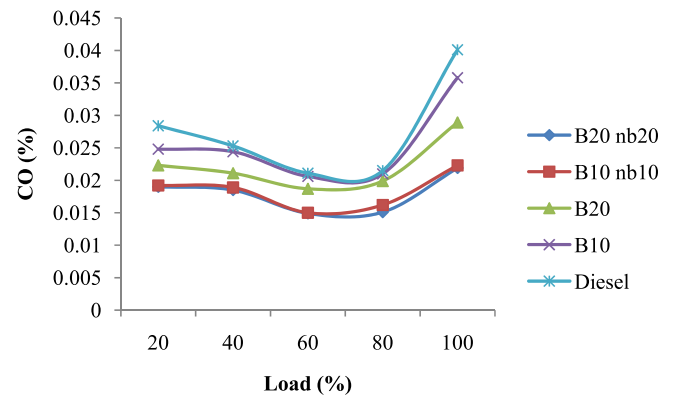


Fig. 4. Variation of CO with load.

5.1.2. Effect on brake thermal efficiency

Brake thermal efficiency is the ratio of brake power output to the energy of fuel consumed. It speaks for the combustion quality of the engine (Mahla et al., 2018b). From Fig. 3 it was noticed that BTE was directly proportional to engine load for all fuel blends. Similar trends were also observed by Bora and Saha (2015) and Dhamodaran et al. (2017). It may be due to the fact that at higher engine loads the cylinder temperature enhances and hence complete combustion is attained which consequently results in higher BTE. Impartial combustion of fuel aids in burning of more fuel and increasing the output of the engine and improving the BTE. It was also found that BTE was higher for B10 fuel blend than natural diesel due to the fact that biodiesel is an oxygenated fuel which aids to complete combustion of fuel, whereas it was lower for B20 in comparison with fossil diesel owing to higher viscosity and lower energy content of biodiesel (Jindal et al., 2015). Improved content of oxygen in fuel contributes to providing more oxygen for proper burning of fuel and bring about an increase in BTE. Due to higher viscosity and lower calorific value of fuel, the combustion of fuel inside the cylinder is not achieved completely which serves in resulting lower BTE. Highest BTE was noticed for B10 fuel blend at full load whereas for fuel blend B20 nb20 lowest BTE was observed at 20% load. BTE was also found to be lower than baseline diesel with the inclusion of n-butanol in all test fuels. It can be attributed to the fact that the cooling effect is generated by n butanol which leads to decreased BTE (Osman Emiroglua and Sen, 2018). Decreased cylinder temperature owing to the cooling effect of n-butanol contributes to impartial combustion of fuel and consequently lower BTE.

5.2. Emission characteristics

5.2.1. Variation of CO with engine load

Carbon monoxide emissions are the result of incomplete combustion of hydrocarbons available in the fuel. Exhalations of CO mainly banks upon air–fuel mixture. When carbon present in the fuel reacts with oxygen inside the combustion chamber, CO is the outcome of the partial combustion. If complete combustion is achieved, carbon and oxygen react to form CO_2 . Exhalations of CO are mainly relying on the air–fuel mixture. Lack of ample air does not allow all the carbon to convert into CO_2 and results in the formation of CO emissions. Fig. 4 depicts that CO emissions firstly decreases with engine load up to a particular limit and then increase with the increase in load. CO emissions decreased owing to low cylinder temperature at intermediate loads which restricts the combustion of hydrocarbons and hence leads to lower CO emissions. The lean air–fuel mixture at higher engine loads bring about partial combustion and hence contributes to increased

CO emissions. Owing to rich fuel–air mixture lesser content of oxygen is provided to the fuel for complete combustion and hence partial combustion is attained. The same trend was observed by Satsangi and Tiwari (2018) and Rakopoulos et al. (2010). It can also be seen that addition of biodiesel in biodiesel–diesel fuel blends is inversely proportional to CO emissions which is very similarly observed by Chauhan et al. (2012) and Chauhan et al. (2013). It may be due to improved combustion of biodiesel in comparison with diesel, as biodiesel contains lower carbon contents and more oxygen particles (Abed et al., 2018). Increased quantity of oxygen and decreased amount of carbon in the fuel aids in providing sufficient oxygen to the combustion products and hence leads to impartial combustion of fuel. As a result of complete combustion owing to the high amount of oxygen in n-butanol, lower CO emissions were detected for fuel blends containing n-butanol (Celebi and Aydin, 2018).

5.2.2. Variation of HC with engine load

Hydrogen and carbon are the main constituents of the diesel fuel. Hydrocarbon emissions are the outcome of partial combustion of fuel inside the combustion chamber (Sakthivel et al., 2017). A lean mixture of air and fuel leads to low flame speeds which results in incomplete combustion, is the primary cause of emissions of hydrocarbons. The deposits of carbon inside the combustion chamber are porous. When the mixture of air and fuel is compressed, some hydrocarbons struck in these pores and do not burn during the power stroke, and are emitted by the cylinder during the exhaust stroke. Fig. 5 shows that for fuel blend B10 HC emissions were found to be lower than baseline diesel whereas for B20 which may be correlated with short ignition delay due to higher cetane number of biodiesel as compared to diesel (Alloune et al., 2017). Shorter ignition delay period brings about more complete combustion of fuel and consequently, lower hydrocarbon exhalations are emitted. Addition of n-butanol in fuel blends attributed in increased HC emissions which may be due to longer ignition delay owing to low cetane number of higher alcohols (Atmanli, 2016). Partial combustion of fuel is achieved as a consequence of longer ignition delay period. The minimum value of HC exhalations was noted for B20 fuel blend at 20% engine load and maximum HC emissions were recorded for B20 nb20 fuel blend at 100% load. For pure diesel highest value of HC emissions was found to be 5.31 g/kWh at 20% load and lowest value of 5.01 g/kWh was observed at full load conditions.

5.2.3. Variation of NOx with engine load

Nitrogen Oxides are the consequences of reaction between oxygen and nitrogen particles inside the engine cylinder especially at

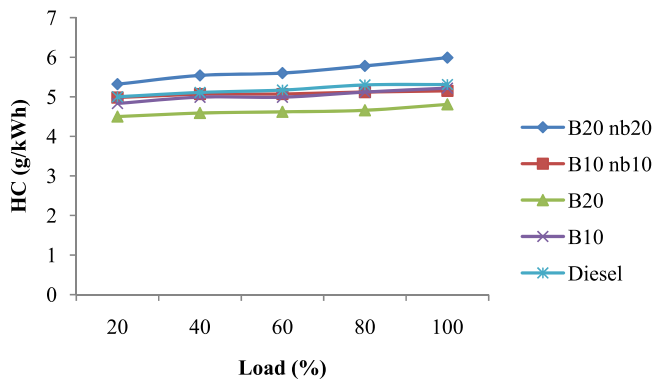


Fig. 5. Variation of HC with load.

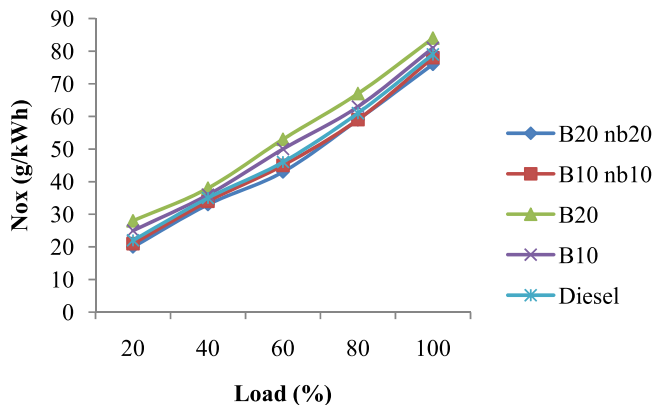
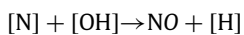
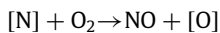
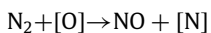


Fig. 6. Variation of NOx with load.

high temperature (Serin and Yildizhan, 2017). As reported by Zeldovich mechanism, the phenomenon of NOx formation in a compression ignition engine is exhibited as following (Mahalingam et al., 2018)



It was established from Fig. 6 that NOx emissions were more for biodiesel blends as compared to diesel which banks on higher combustion temperature of biodiesel (Nabi Nurun et al., 2017) and higher unsaturation degree (Jeevahan et al., 2018). Increased temperature of combustion leads to the reaction of oxygen and nitrogen atoms at a higher rate. Minimum and maximum values of NOx emissions were recorded for B20 nb20 and B20 fuel blend at 20% and 100% load respectively. NOx emissions were found to be on higher side with the increase in engine load whereas inclusion of n-butanol helps in trimming down NOx emissions. Reason for later can be lower viscosity and higher heat of vaporization of n butanol which results in better atomization properties and decreasing the combustion temperature respectively (Jiaqiang et al., 2017). Superior atomization properties result in improved combustion and, inferior combustion temperature aids in minimizing the reaction between nitrogen and oxygen.

5.2.4. Variation of smoke with engine load

Incomplete combustion of fuel aids in producing smoke which helps in originating smoke opacity (Chauhan et al., 2016). It is an unintended measure of existence of soot particles in the exhaust. Fig. 7 presents an increased trend of smoke emissions with the increase in load which is due to the high utilization of fuel at higher

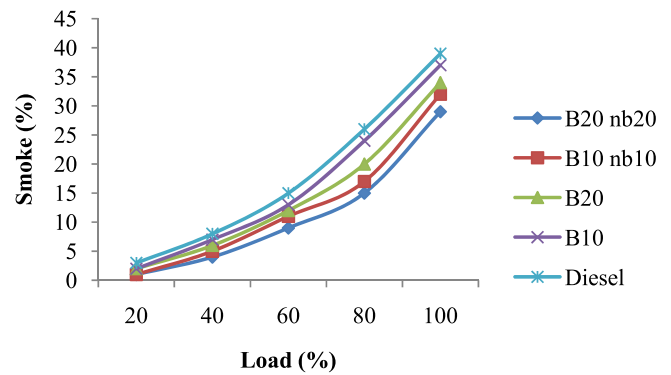


Fig. 7. Variation of smoke with load.

loads. When excess fuel enters inside the combustion chamber at high engine loads it results in partial combustion of fuel and consequently more smoke emissions. Fossil diesel was found to have the maximum value of smoke opacity at full load whereas the minimum value of smoke emissions was noted for B10nb20 fuel blend at 20% engine load. Fuel blends with biodiesel were having decreased level of smoke emissions than pure diesel owing to a higher amount of oxygen in biodiesel which helps to achieve complete combustion of fuel (Abed et al., 2018). There was a further decrease in smoke opacity with the inclusion of n-butanol in the fuel blends which may be the result of the higher oxygen content of n-butanol (Zheng et al., 2015; Rai et al., 2013a). More quantity of oxygen in fuel aids in supplying ample amount of oxygen atoms to the combustion products and consequently results in complete combustion of fuel.

6. Conclusions

An experimental investigation was performed on a single cylinder diesel engine using rice bran biodiesel and n butanol blends B10, B20, B10 nb10, B20nb20. Performance and emissions characteristics were noted at various engine loads and BSFC, BTE, CO, HC, NOx, and smoke were compared with diesel fuel. Following was concluded:

1. Brake specific fuel consumption increased with increase in the quantity of biodiesel and n-butanol in the blends and is higher than diesel fuel.
2. Brake thermal efficiency enhanced up to addition of 10% biodiesel in fuel blends and lowered with the addition of 20% biodiesel in fuel blends, and it was lesser than diesel for blends having n-butanol.
3. Carbon monoxide emissions and smoke were found to be decreased with the inclusion of rice bran biodiesel in the blends and were further decreased with n-butanol.
4. Blends with rice bran oil also found to reduce hydrocarbon emissions, but with addition of n-butanol it increased.
5. Nitrogen oxide emissions reported more by adding biodiesel in fuel blends whereas blends having n-butanol shows a decrement in same.

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