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Experimental Assessment on Replacement of Diesel Fuel With 20% Blend of Castor Biodiesel In An Existing Single Cylinder CI Engine

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Abstract

Biodiesel has been proved to be the most viable substitute of dieselfuel with minor or no modifications of compression ignition (CI engine). Viscosity is the major issue for the use of neat biodiesel in the existing CI engine and researchers usually make an agreement for the optimum mixing of biodiesel in the diesel fuel. In most of the studies, 20% mixing of biodiesel optimum mixing in terms of engine performance and emissions reduction irrespective of feedstock the biodiesel. In this study, biodiesel is prepared from castor oil which is considered to be the most viscous oil. The basic physical properties of castor biodiesel have been evaluated as per ASTM standards. The 20% castor biodiesel by volume (B20) is blended with diesel and tested in constant rpm single cycle CI engine. An optimum load condition has been investigated at which B20 gives the best results. After that at optimum load condition B20 was tested for various fuel injection timings in order to judge whether any operational modification is required.

Introduction

The oil reserves in the world are sufficient to meet only 50 years (approx.) of the global energy demand. In India, the total proved reserves of oil are sufficient to meet only 13 years of its demand. The demand and cost of crude oil is expected to rise more rapidly in the near future than the current trend. On the other hand, the air pollutants caused by combustion of fossil fuels are becoming the leading environmental risk factor for living beings. These issues needs an alternate which is renewable and non-polluting which can be supplemented or replace the conventional energy resources and reduce our dependency on fossil fuels.

Experiments have been conducted with a number of vegetable oils as fuel supplement in CI enginesuch as Jatropha,mahua, karanja, rapeseed, soybean, neem, coconut, sunflower, rice bran, palm, rubber seed, etc. and showed an acceptable performance over a short period of time in unmodified diesel engine[1–14]. With neat jatropha oil, the brake thermal efficiency (BTE) was recorded as 27.4%, 29% with biodieselof jatropha oil and both diesel and jatrophabhiodiesel it was 28.7% [15].Usta[16] studied the performance and emissions of CI engine using biodiesel from hazelnut soapstock and found that the optimum biodiesel addition for maximum power output was 17.5% by volume. He et al. [17] found that 30% mixing cottonseed oil in diesel was practically optimal to ensure relatively high BTE.Saravanan et al.[18]conducted experiments using biodiesel from rice bran oil to analyze the combustion behaviorand found 20% blending as optimum.Panwar et al. [19]examinedthe performance and emissions of CI engine fueled with blends (B05, B10 and B20) castor biodiesel with diesel and compared with that of diesel fuel (B0). In this study, B10 fuel blend proved as optimum one. So, there is no generalized statement given by any of the study. Each study has its own opinion because each biodiesel has its unique properties.

Experiments have also been conducted by varying injection strategies. Narayana Reddy et al. [20] conducted experimentswith Jatropha oil fueled CI engine. It was found that a significant enhancement in engine performance and reduction in emissions was there when the injection timing is retarded and injection rate is increased.Sahoo and Dass[21] found that neat Karanja and Polanga biodiesel were having shorter ignition delay than diesel.

In the present study, the biodiesel is prepared from castor oil and is mixed with diesel by 20% of total volume (B20). Engine performance, emissions are evaluated using B20 and the results are compared with diesel fuel.

Experimental Methodology

Castor oil is obtained from castor seeds through mechanical extraction. The raw castor oil is then filtered to separate out the unwanted contaminates. The biodiesel is prepared by single step transesterification. The castor biodiesel and diesel is then mixed mechanically to make the desired blend B20. The physio – chemical of B20 and diesel are shown inTable *1*. The engine chosen to carry out experimentation is compression ignition engine at constant speed which is generally used for various applications in agriculture and domestic power generation purposes. The various load conditions taken for engine testing are: 2%, 20%, 40%, 60%, 80% and 100% of full load. The objective here for the substitution of pine oil in diesel fuel without degrading the engine performance and subsequent reduction in exhaust emissions.The setup is being equipped with data acquisition system and has capabilities to evaluate combustion and performance parameters. Thermodynamic analysis of measured cylinder pressure data was done for quantifying the various related combustion parameters. In this study the emissions of major concern only i.e. NOx and Smoke were evaluated. AVL Di-Gas 4000 LIGHT analyzer was used for NOx measurements and AVL 437 smoke meter was used for smoke opacity. Further, the experimental investigations are also performed with the alteration of injection timing viz. 2° advanced and retarded from the default injection timing i.e. 23° BTDC. The pictorial representation has been shown in Figure *1*.

Table 1. Properties of Diesel and B20

Property	Diesel	B20	Standard Used
Kinematic viscosity at 40°C (cSt)	2.6	4.47	ASTM D 1250
Density at 15°C (g/m^3)	0.826	0.845	ASTM D445
Flash Point (°C)	68	75	ASTM D93
Net Calorific Value (MJ/kg)	44	41.3	ASTM D240

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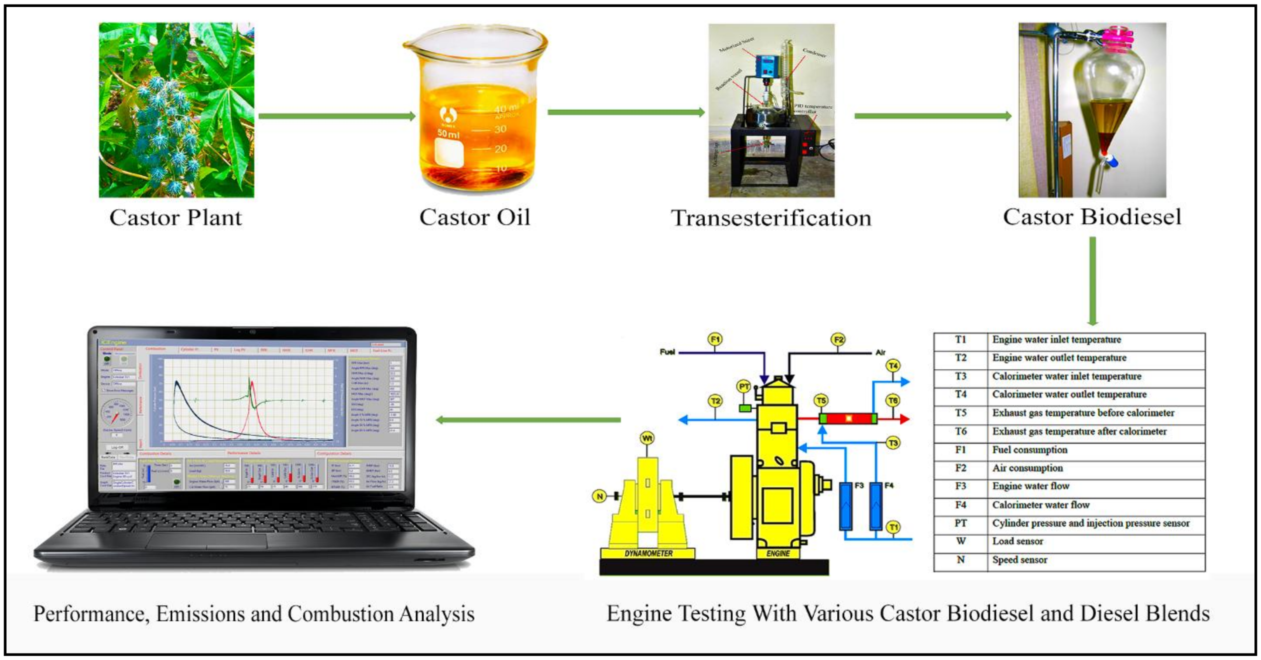

Figure 1. Pictorial representation of experimental methodology.

Results and Discussion

The kinematic viscosity (as shown in Table 1) for B20 is very close to the maximum limit proposed in ASTM D6751 (6 cSt). Higher flash point for B20 than diesel fuel makes it safe from the storage and handling point of view. The fuel blend was stable and homogeneous after 48 hours and there were no signs of phase seperation observed during this observation period.

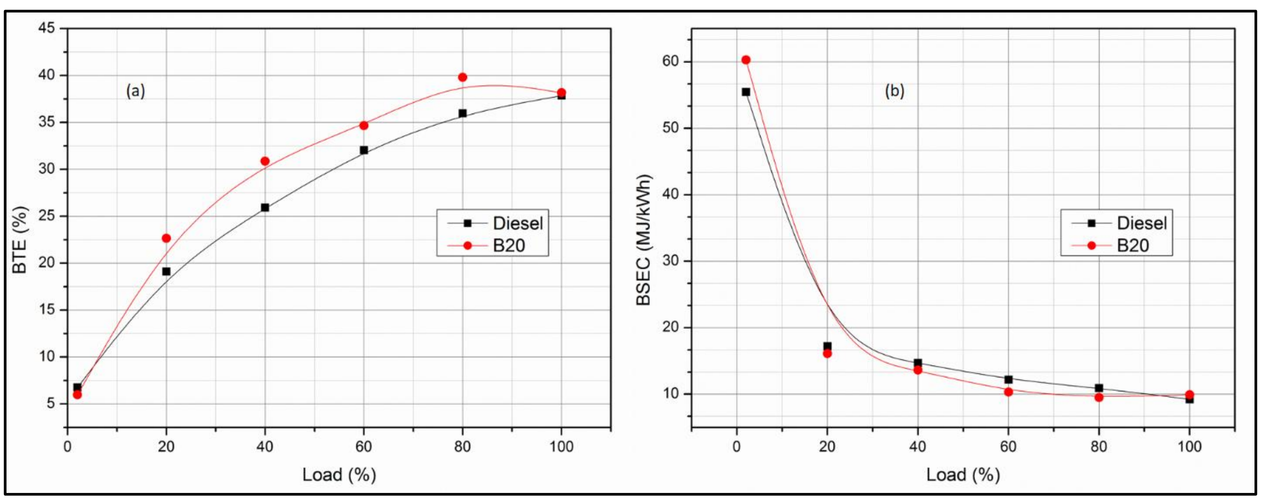

Figure 2. (a) BTE vs Load; (b) BSEC vs Load.

From figure 2, it has been noticed that the efficiency (BTE) of B20 is on higher side by 4% (approx.) in comparison to diesel at all the tested load conditions. Consequently, the BSEC is slightly on the lower side. The reason for this may be observed from figure 3. The maximum cylinder pressure for B20 is on higher side than that of diesel fuel. The fraction of fuel which is taking part during the uncontrolled combustion influence the peak pressure inside the cylinder [22].The ignition delay of B20 fuel is observed to identical to that of diesel. The rise of the curve for uncontrolled combustion phase and peak point of HRR for B20 fuel appeared to be closer to TDC which means faster combustion rate. It indicatesthatmaximum heat is being added near to TDC during the cycle and hence higher BTE for B20 fuel blend.It also shows that the BTE is not just dependent on the amount of heat energy released during the cycle butalso on the crank angle at which the heat is being added[6,23].

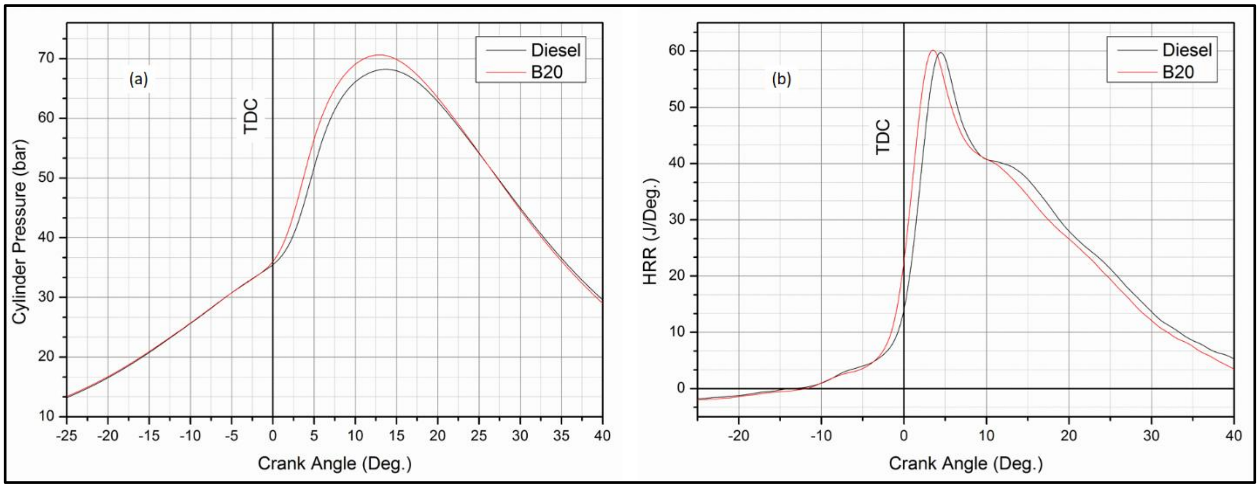

Figure 3. (a) Cylinder Pressure vs. Crank Angle; (b) Heat Release Rate vs. Crank Angle at 80% of full load.

The trends of CO and HC, in Figure 5, for both the test fuels are slightly lower at low loads and approximately identical at higher loads. It may be attributed to the fact that during uncontrolled combustion the slope of B20 is almost identical to that of diesel and the peak HRR is also identical. The improvement in performance is attributed to timing only. The similar trends and observations are also mentioned in some of the related studies [24–26].The trends of NOx emissions and smoke opacity for B20 fuel are on lower side to that of diesel. As mentioned earlier that uncontrolled combustion happens closer to TDC, so the heat energy in the cylinder is more likely to be converted into the mechanical energy. It limits the release of waste heat energy and gas temperature and hence less NOx emissions. It is a well-established fact that the smoke is result of available energy during the diffusive combustion phase [27,28].Higher the available energy during diffusive combustion more will be the smoke generation. In Figure 4, HRR curve shows that the after peak point the available energy for B20 fuel during diffusive combustion is slightly on the lower side than that of diesel and hence lower smoke opacity. The smoke reduction can also be attributed to less carbon present in castor biodiesel in comparison to diesel. Also, the absence of aromatic compounds in castor biodiesel causes less smoke generation. More the carbon in a fuel molecule, more likely it is to produce the soot [29].

The combustion, performance and emission parameters of B20 only is also investigated with varying injection timings (ITs) at 80% of full load as shown in Figure 7 – Figure 8. The change in ITs results in significant effect on trends of cylinder pressure.It has been observed that advancing the ITs results in high peak cylinder pressure.The effect of advancing the IT be

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observed during the uncontrolled combustion phase for both the fuels. The slope of HRR curve for B20 is identical to diesel but it is closer to TDC.

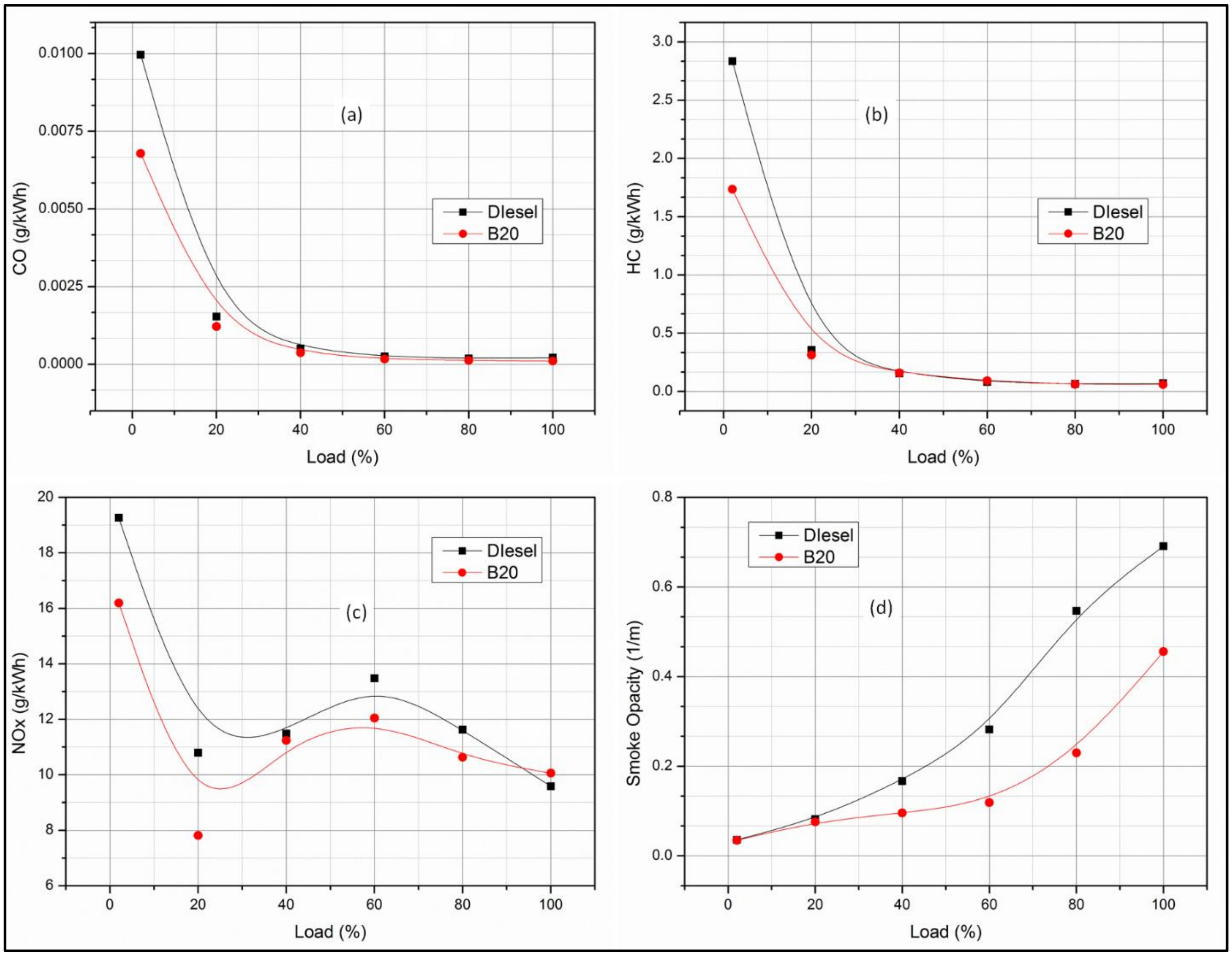

Figure 5. Variation of brake specific emissions w.r.t. engine load.

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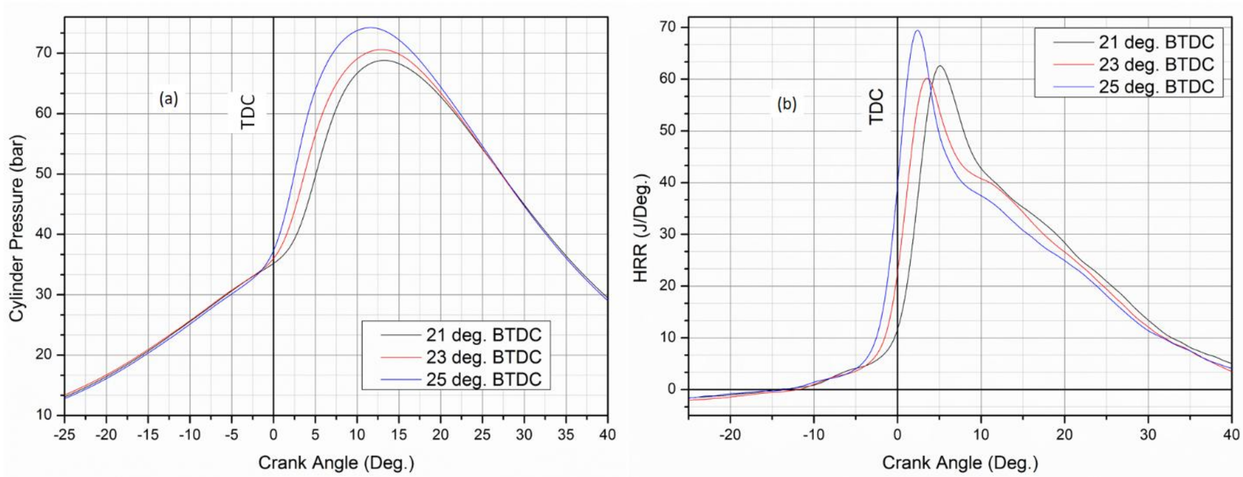

Figure 6. Variation of (a) Cylinder Pressure vs. Crank Angle; (b) Hear release rate vs. Crank Angle at different injection timings.

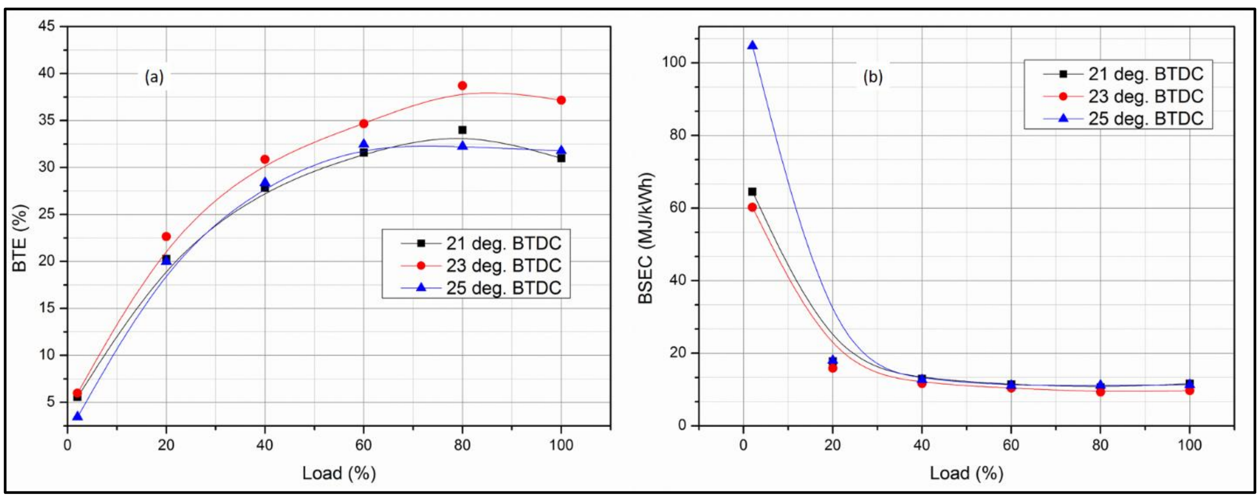

Figure 7. (a) BTE vs Load; (b) BSEC vs Load at different injection timings

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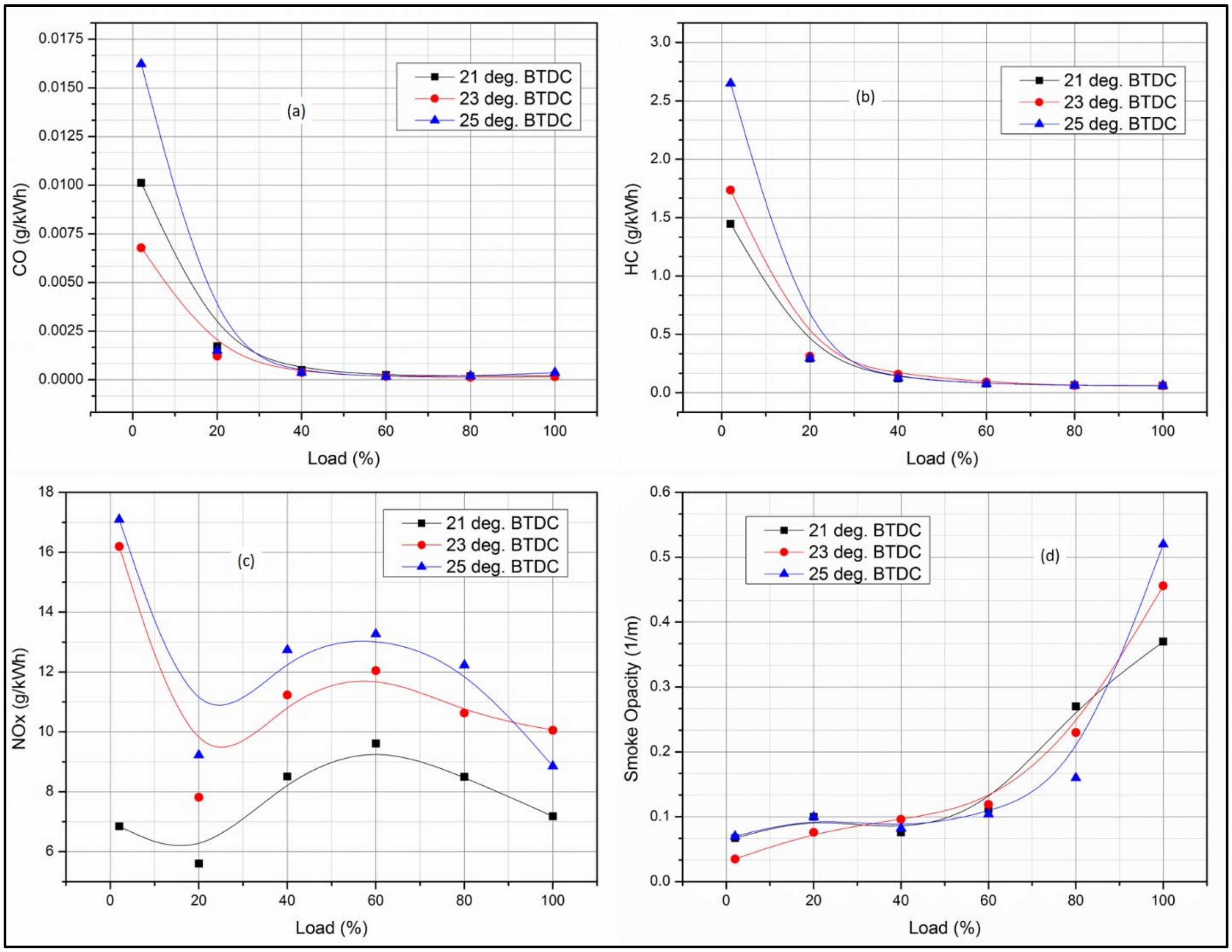

Figure 8. Variation of brake specific emissions w.r.t. engine load.

The early rise in HRR curve was observed with advancing of fuel injection and similarly delayed rise in HRR curve was observed with retarded fuel injection. The almost 50% of the heat energy which is being released by the B20 fuel prior to reaching the piston up to TDC during compression stroke and remaining one is releasedduring expansion stroke when the injection timing is set to 25° BTDC. Due to early combustion, at 25° BTDC, the heat from combustion products is transferred to the cylinder walls and crevice. This heat has been released during the late combustion zone and hence results in lower BTE. At retarded injection timing,the maximum amouont the heat is being releasedbeyond the TDC therefore the heat energy conversion to useful mechanical work get reduced. There is no significant difference in the trends of CO, HC and smoke opacity with alteration of IT from 20% to 100% engine load. On the other hand, NOx decreases as the injection timing is retarded. The high in-cylinder temperature and residence time of hot gases inside the cylinder during combustion stroke is the main reason for NOx emissions [30,31]. Therefore, advancing ITs, the high temperature resides inside the cylinder for relatively longer duration and hence increase NOx.

Conclusions

In the present experimental study the following conclusions have been drawn:

- B20 blend exhibits better thermal efficiency and with lower BSEC than that of diesel due to its peak cylinder pressure and maximum amount of release of heat energy near to TDC.
- The overall trends of CO and HC emissions for B20 arein close agreement to that of diesel, however, the trends of NOx emissionsin case of B20 are on lower side. The smoke opacity for B20 was observed to be significantly lower than that of diesel.
- There is slight decrease in BTE advanced as well as retardedinjection timings but there is no BSEC trends ore almost identical.
- The significant change in CO, HC and smoke opacity has not been noticedat all the tested fuel injection conditions, however, NOx is minimum at IT 21° BTDC but against the penaltyof decrease in BTE.
- B20 fuel shows the better performance than that of diesel at default injection configuration therefore no design modifications are required.

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