Journal of Energy and Environmental Sustainability, 3 (2017) 66-70

An official publication of the International Society for Energy, Environment and Sustainability (ISEES)

Journal of Energy and Environmental Sustainability

Journal homepage : www.jees.in

Effect of Fuel Oxygen Content on the Performance of a CI Engine Operating on Soapnut Biodiesel Blends

B. P. Pattanaik[1*], J. Jena[2] and R. D. Misra[1]

[1]*Department of Mechanical Engineering, National Institute of Technology Silchar, Silchar–788010, Assam*
[2]*Department of Mechanical Engineering, Gandhi Institute for Education and Technology, Khurda–752060, Odisha*

ARTICLE INFO

Received : 08 May 2017
Revised : 03 June 2017
Accepted : 09 June 2017

Keywords:
Soapnut biodiesel, diesel engine, engine performance, NO_x emissions, fuel oxygen content

ABSTRACT

In the present work,18 numbers of soapnut biodiesel-diesel blends along with soapnut oil as additive in some cases were used in a compression ignition engine forcomparative assessment of the effect of fuel blends on the engine performance. Considering the large variations in oxygen content of the fuel blends it was opted as the basis for the study. Results showed that the best engine performance is achieved with oxygen content in the fuel blends in the range 1.8–3.0%. The emission results showed that the best engine emission is obtained for oxygen content in the fuel blends in the range 0.71–2.37%. Considering engine performance and emissions, the critical zone of oxygen content was found to be in the range 1.8–2.37%. The fuel blends having oxygen content within this critical zone, i.e. fuel blend nos. 8–13 were found to be best with higher engine performance and lower exhaust emissions.

1. Introduction

Progress in science and technology over the years has changed human life style which in turn has considerably raised the global energy consumption. The demand for fossil fuels has accordingly increased thereby resulting in faster depletion of the conventional fossil fuel reserves. Further, increase in greenhouse gas percentage in the atmosphere as a result of fossil fuel combustion has raised serious concerns for the ecosystem. These factors have led to an innovative worldwide search for alternative fuels from renewable sources especially biomass. The major biofuels derived from biomass are biodiesel, bioethanol, biogas, producer gas etc. In particular, biodiesel derived from vegetable oils has come out as a promising alternative fuel for diesel engines in recent years. Biodiesel is the fatty acid methyl ester which is derived from vegetable oils or animal fats via base catalyzed transesterification [Demirbas 2007]. It is a renewable, biodegradable, and non-toxic fuel and has comparable fuel properties to diesel. Biodiesel has edge over diesel fuel due to its higher flash point and greater lubricity [Canakci and Sanli 2008]. However, higher viscosity and poor cold flow properties make it unsuitable for use in cold climates. Owing to this use of neat biodiesel in diesel engines is not recommended for long term use. On the other hand, biodiesel exhibits lower carbon monoxide (CO), unburned hydrocarbons (HC), and particulate matter (PM) emissions compared to diesel. However, it leads to slightly higher nitrogen oxides (NO_x) emissions owing to its higher oxygen content [Babu and Devarajane 2003; Ribeiro et al. 2007; Murugesan et al. 2009; Atadashi et al. 2010; Ferella et al. 2010]. Due to these factors use of biodiesel as blends with diesel up to certain volume percentages is more suitable rather than use of neat biodiesel as fuel in a compression ignition (CI) engine.

Literatures depict that the oxygen content in biodiesels has a great influence on its physio-chemical properties and the combustion and emission characteristics. Biodiesels are reported to contain 10–12% oxygen on weight basis [Usta et al. 2005; Sendzikiene et al. 2006; Özener et al. 2014]. Due to their higher oxygen content, biodiesels exhibit higher viscosity and poor cold flow properties leading to gel formation at low temperatures which results in fuel pumping issues and congestion of filters [Joshi and Pegg 2007; Dwivedi and Sharma 2013]. On the other hand, presence of higher oxygen in biodiesels and a higher cetane number ensure more complete combustion resulting in superior power output and thermal efficiency along with lower CO, HC and PM emissions compared to those with diesel fuel [Kalam et al. 2003; Kalligeros et al. 2003; Sendzikiene et al. 2006; Nabi et al. 2006; Helwani et al. 2009; Gumus et al. 2012]. However, availability of higher oxygen and complete combustion in case of biodiesels lead to higher combustion temperatures and subsequently higher NO_x formation [Glaude et al. 2010; Qi et al. 2010; Hoekman and Robbins 2012; Dhar et al. 2012; Yilmaz et al.

* Corresponding Author: *bpprdmnits@gmail.com*

2014]. Thus, it is evident from the literature that higher oxygen content in biodiesels is advantageous to the conventional diesel fuel from several view points. However, it also has some major detrimental effects which restrictthe use of biodiesels as blended fuel with diesel. Thus, there is a need for evaluating the correct oxygen content in biodiesel fuels in order to achieve better engine performance with lowest exhaust emissions.

In the present work experiments were carried out on a CI engine fuelled with a number of soapnut biodiesel-diesel blends with an objective to study the influence of the oxygen content present in the fuel blends on the engine performance and emission characteristics. The major objective of the present study was to evaluate the most appropriate fuel oxygen content for a CI engine to achieve best engine performance along with lower exhaust emissions. Additionally, the role of parent vegetable oil as an additive to biodiesel-diesel blends was also studied in order to establish the most suitable additive percentage for achieving best engine performance and emissions. Though literature suggest that 20% biodiesel with diesel is known to be the best biodiesel blend having similar engine performance along with superior emission to that of diesel [Manieniyan and Sivaprakasam 2008; Sakthivel et al. 2015], in the present work it was experimentally verified that percentage of biodiesel in biodiesel-diesel blends can be successfully enhanced from 20% upto 25% with at par engine performance and lower exhaust emissions compared to diesel fuel.

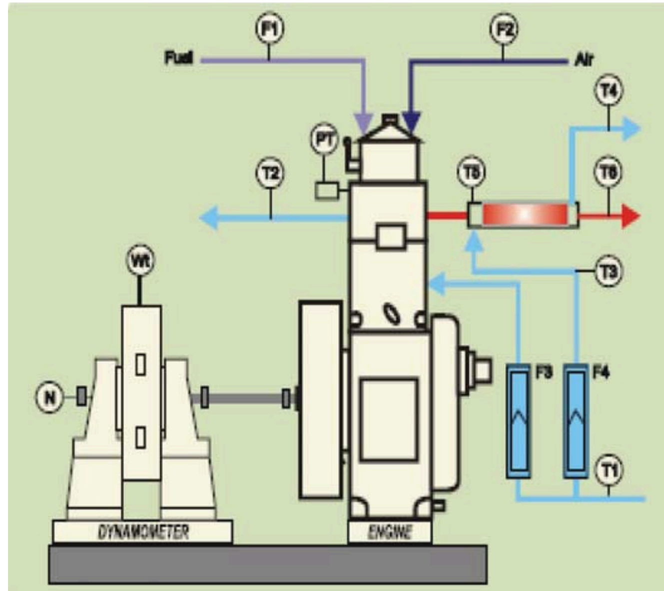
2. Materials and methods

2.1 Fuel samples

For the present experimental investigation soapnut oil (SO) was selected as the biofuel source. The purpose of selecting SO in this work is its availability and cost in this locality, being non-edible in nature, and being a newly established biofuel source. Neat SO was used for production of soapnut biodiesel (SB) via base catalyzed transesterification. The prepared SB was then blended with diesel in predefined volume percentages of 10%, 15%, 20%, 25%, 30% and 40% and were suitably named as SB10, SB15, SB20, SB25, SB30, SB40, along with SB100 i.e. 100% biodiesel. Parent vegetable oil known as SVO i.e. SO was then used as an additive in small volume percentages of 2.5%, 5%, and 10% to the already prepared biodiesel blends i.e. SB10, SB15, SB20, and SB25 to prepare a number of resulting fuel blends which are named as SB10-SO2.5 (10% by vol. of SB, 2.5% by vol. of parent SVO and the rest diesel), SB10-SO5, and SB10-SO10. SB15 blends with parent SO as additive are termed as SB15-SO2.5, SB15-SO5, and SB15-SO10 and so on. In this way, a total number of 18 final fuel blends were prepared for the present experimental investigation namely SB10, SB10-SO2.5, SB10-SO5, SB10-SO10, SB15, SB15-SO2.5, SB15-SO5, SB15-SO10, SB20, SB20-SO2.5, SB20-SO5, SB20-SO10, SB25, SB25-SO2.5, SB25-SO5, SB25-SO10, SB30, and SB40.

2.2 Experimental setup

In the present work a single-cylinder four-stroke water cooled diesel engine was used for evaluating the performance and emission characteristics of all the 18 numbers of prepared fuel blends along with diesel. The test engine was coupled with an eddy current dynamometer and the loading was controlled by a load console. Two separate fuel tanks were used along with a two-way fuel supply line for supplying SB blends and diesel separately to the engine. A five gas analyzer (AVL Digas 444) and an AVL 437 smokemeter were connected to the test engine for measuring the engine emissions. The entire engine test was operated by Engine soft LV software installed on a computer. For better understanding, a schematic diagram of the experimental engine setup is presented in Fig. 1 followed by its technical specifications given in Table 1.



F 1: Fuel injection pressure sensor, F2: Air flow meter, T1: Cooling water inlet temperature to engine and calorimeter, T2: Cooling water outlet temperature from engine, T3: Cooling water inlet temperature to calorimeter, T4: Cooling water outlet temperature from calorimeter, T5: Exhaust gas inlet temp to calorimeter, T6: Exhaust gas outlet temp from calorimeter, PT: Piezo sensor, N: rpm pick up and TDC encoder, F3: Water flow meter for engine, F4: Water flow meter for Calorimeter

Fig. 1 The experimental engine setup

Table 1 Specifications of the test engine

Engine parameters	Description
Engine type	Single cylinder, 4-stroke, water cooled, direct injection, naturally aspirated
Make	Kirloskar, TV1 model
Dynamometer	Eddy current, water cooled, with loading unit
Bore×Stroke	87.5 mm×110 mm
Compression ratio	17.5
Connecting rod length	234 mm
Displacement	0.661 litre
Rated power	5.2 kW
Rated speed	1500 rpm
Fuel injection type	Single barrel F.I. pump, inline fuel injector
Injection timing	23°BTDC
Inj. opening pressure	20.5 MPa
Injector hole dia.	3×0.288 mm
Orifice dia.	20 mm
Dynamometer arm length	185 mm
Rotameters	Engine cooling 40-400 LPH, Calorimeter 25-250 LPH

3. Results and discussion

3.1 Fuel characterization and CHO analysis

The preparation of the desired 18 numbers of fuel blends was followed by fuel characterization using standard ASTM methods. From the fuel characterization results it was evident that the density, viscosity, cloud point, and pour point of the fuel blends increase with increase in oxygen content. The density and viscosity of all the fuel blends were observed to be in the range 837-855 kg/m^3 and 3.05-4.16 cSt respectively. Similarly, the cloud and pour points of all the fuel blends were found to be in the range 7.0-12.6°C and 3.5-4.9°C respectively. Again, gradual decrease in calorific value of the fuel blends was observed with increase in oxygen content. The calorific value of all the fuel blends was noticed to be varying in the range 40.74-42.5 MJ/kg. However, critical observations of the results clearly depict that all the selected fuel blends exhibit comparable physio-chemical properties with diesel.

The fuel characterization tests were followed by evaluation of carbon, hydrogen, and oxygen percentages present in the fuel blends. A CHN-O elemental analyzer (Model-Flash 2000) was used for estimating these components for each of the fuel blend sample. The percentage oxygen contents for each of the fuel blends obtained from the elemental analysis are demonstrated in Table 2. In Table 2 the fuel blends are reordered according to the increasing oxygen content and accordingly their blend

Table 2 Percentage oxygen content in the prepared SB blends

Fuel blend No.	Fuel blend name	% by volume			Oxygen (% by wt)
		SB	Diesel	SO	
1	SB10	10	90	0	0.961
2	SB10-SO2.5	10	87.5	2.5	1.210
3	SB15	15	85	0	1.240
4	SB15-SO2.5	15	82.5	2.5	1.469
5	SB10-SO5	10	85	5	1.499
6	SB20	20	80	0	1.686
7	SB15-SO5	15	80	5	1.748
8	SB10-SO10	10	80	10	1.809
9	SB25	25	75	0	2.010
10	SB20-SO2.5	20	77.5	2.5	2.060
11	SB15-SO10	15	75	10	2.309
12	SB25-SO2.5	25	72.5	2.5	2.329
13	SB20-SO5	20	75	5	2.377
14	SB30	30	70	0	2.410
15	SB20-SO10	20	70	10	2.648
16	SB25-SO5	25	70	5	2.830
17	SB40	40	60	0	3.070
18	SB25-SO10	25	65	10	3.602

number is assigned for future reference. From the CHO analysis it was observed that the variation in oxygen content of all the 18 numbers of fuel blends is very large i.e. 78.23%. Therefore, it is relevant to use the variations in oxygen percentage as the basis for the comparative assessment of the effect of the SB blends on the performance of the engine.

3.2 Effect of fuel oxygen content on engine performance parameters

From the results it is observed that there is a wide variation in the ranges of values of the different performance and emission parameters, although qualitatively similar, against varying percentage of oxygen in the fuel blends. Therefore, it is necessary to bring down these parameters to a common platform for their comparative assessment. It is a normal practice to bring the varying coordinate axes of different parameters on the same coordinate axes by non-dimensionlizing them. Since diesel is the base fuel of all the selected fuel blends in the present work, all the parameters of a particular fuel blend were non-dimensionlized by dividing the corresponding value of diesel. That is, the value of i^{th} parameter of a specific fuel blend can be found as:

$$\left(\beta_{specific\ biodiesel\ blend}\right)_i = \frac{i_{specific\ biodiesel\ blend}}{i_{diesel}}$$

Where, β_i is known as the non-dimensionilized parameter for the i^{th} parameter of a specific fuel blend.

The variations of different engine performance parameters like brake thermal efficiency (BTE), brake specific energy consumption (BSEC), and exhaust gas temperature (EGT) against varying percentage of oxygen content in the fuel blends as obtained from experimentations with the considered fuel blends are presented in Fig. 1 along with necessary discussions on the presented results.

3.2.1 Brake thermal efficiency

BTE is a very significant engine performance parameter as it measures the true power output obtained from the engine shaft. It also specifies the engine ability to transfer the fuel chemical energy into mechanical power. It was observed that BTE of the fuel blends exceeds to that of diesel at about 1.97% oxygen content in the SB blends. It was also observed that $(\beta)_{BTE}$ increases with increase in oxygen percentage up to 2.37% for the SB fuel blends. This is in agreement with the results obtained by Di et al. [2009]. With increase in oxygen percentage in the fuel blends the heating value decreases and less fuel energy is supplied to produce a fixed brake power. Further, it was observed that the fuel blends containing oxygen more than 1.97% show higher BTE than diesel. One possible explanation could be that because of higher density of biodiesel blends compared to that of diesel, more quantity of biodiesel is required to be supplied to compensate the decreased heating value of the fuel blends.

3.2.2 Brake specific energy consumption

BSEC is defined as the ratio of the energy obtained by burning of fuel in an hour to the actual energy developed by the engine or brake power. BSEC is reported to increase with increase in biodiesel percentage in the blends i.e. with increase in oxygen content in the fuel [Sahoo et al. 2009; Sayin and Gumus 2011]. However, the present results depict that $(\beta)_{BSEC}$ decreases with increase in oxygen percentage up to 2.37% for SB blends. The fuel blends with oxygen percentage more than 1.97% perform better showing lower BSEC than diesel. The reason for the decrease is due to decrease in heating value. The fuel blends with oxygen percentage more than 2.37% showed slight increase in $(\beta)_{BSEC}$. For these fuel blends, the increase in density and viscosity dominates the gain in heating value and because of which the fuel consumption increases slightly. From the above results it seems that the fuel blends containing oxygen higher than 1.97% and below 2.37% show lower BSEC than other fuel blends.

3.2.3 Exhaust gas temperature

From the literature it is evident that EGT increases with higher biodiesel percentage in the blended fuel [Raheman and Ghadge 2007; Nabi et al. 2009]. In the present work it was observed that decreases with increase in oxygen percentage up to2.37% for SB blends and then show slight increasing trend. The reason to this decrease may be the increase in stoichiometric fuel–air ratio with the increase in oxygen content in the fuel blend causing the mixture faster to reach the stoichiometric conditions [Raheman and Phadatare 2004]. It is observed that the most preferable fuel blend is the fuel blend number 13, which shows the lowest than among their corresponding fuel blends.

Thus considering all the engine performance parameters it seems that the best engine performance for the region of oxygen content from 1.8–3.0% irrespective of fuel types, wherein the BSEC for the fuel blends is in the minimum range as well the BTE is in the maximum range.

3.3 Effect of fuel oxygen content on engine emissions parameters

Exhaust emissions like CO, HC, NO_x, smoke opacity etc. are the primary issues on successful performance of CI engines. Literature shows that biodiesels significantly reduce HC and CO emissions compared to the diesel. However, NO_x emission increases slightly with biodiesel in comparison with diesel. It is found from the literature that parent vegetable oil as additives in biodiesel blends may be one of the possible options to reduce NO_x emissions [Misra and Murthy 2011]. In the present section the non-dimensionalized emission parameters $(\beta)_{CO}$, $(\beta)_{HC}$, $(\beta)_{CO_2}$, $(\beta)_{NOX}$, $(\beta)_{PM}$ and for the considered SB blends with respect to increase in oxygen content are shown in Fig. 2 followed by detailed explanation of the results in the following subsections.

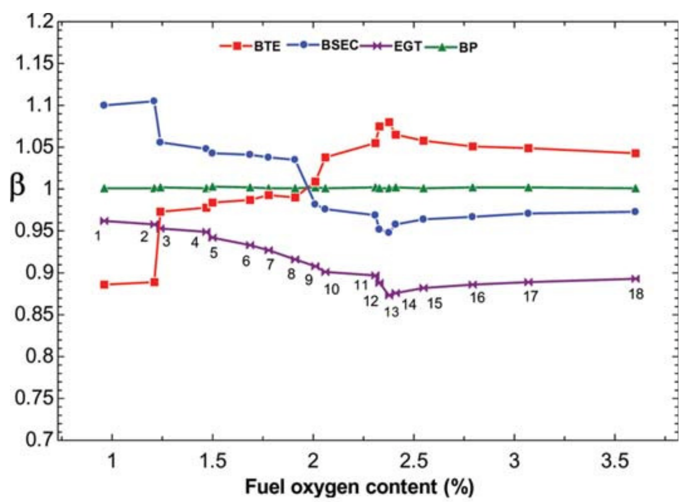


Fig. 2 Variation of $\beta_{engine\ performance\ parameters}$ with fuel oxygen content

3.3.1 CO emissions

It is observed that with the increase in oxygen percentage in the fuel blends the CO emissions reduce gradually. This may be due to lower carbon content for biodiesel blends compared to diesel. Thus with less carbon in the fuel, there is a better chance that each carbon atom will find two oxygen atoms to bind to form CO_2. Another possible reason could be during combustion there may be lower possibility of formation of rich fuel zone with the biodiesel fuel blends due to the presence of fuel oxygen, and thus CO emissions get reduced [Karabektas 2009]. The reductions in CO emissions with increase in fuel oxygen content are in agreement with the published literatures [Kumar et al. 2003; Gumus and Kasifoglu 2010]. It was observed that for the fuel blends containing more than 2.37% oxygen content show a sharp reduction in CO emission compared to diesel.

3.3.2 CO_2 emissions

The results show that the CO_2 emission increases, with the increase in oxygen percentage in the SB blends. The CO_2 emissions for all selected fuel blends are less than that with diesel. This is attributed to the fact that biodiesels are low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel. The fuel blends having oxygen content less than 2.32% show comparatively lower CO_2 emissions. However, beyond these oxygen percentages all the fuel blends show a quick rise in CO_2 emissions, which may be attributed to higher oxygen percentage in the fuel blends and in agreement with the published literature [Xue et al. 2011].

3.3.3 HC emissions

Literature on CI engines studies agreed that engines running with biodiesel fuel blends result lower HC emissions compared to diesel [Xue et al. 2011]. From Fig. 3 it is observed that the HC emissions reduce with increase in oxygen percentage in the fuel blends. The HC emissions for all considered fuel blends are less than diesel, because the major source of HC emission is over-mixing. Over-mixing is strongly linked with ignition delay as well as with the mixing of air and fuel during combustion period. Both shorter ignition delay and better atomization are responsible for complete combustion and reduced HC emissions [Monyem et al. 2001; Abd-Alla et al. 2001]. It is also observed that at oxygen percentages higher than 2.37% (blend number 13–18) the HC emissions are better than those of other fuel blends with the fuel blend number 18 showing lowest HC emission.

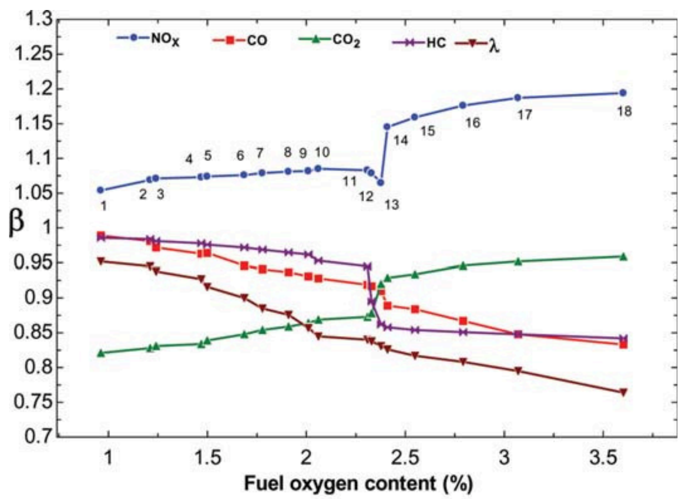


Fig. 3 Variation of $\beta_{\text{exhaust emission parameters}}$ with fuel oxygen content

3.3.4 NO_x Emissions

From Fig. 3 it is observed that NO_x emissions increase with increase in oxygen percentage of all the SB blends and are higher than that of diesel. The possible reasons to this may be advanced injection timing, higher CN, higher viscosity, presence of oxygen and shorter ignition delay [Xue et al. 2011; Hoekman and Robbins 2012]. Advancing of injection timing is responsible for advancing the start of combustion. This may produce higher peak temperature inside the cylinder and may increase the rate of NO_x production. This also results in a longer residence time, allowing NO_x production to continue for more time. Further, higher CN of biodiesel fuel blends shorten ignition delay and thus start of combustion advances. This results in a significantly longer residence time of higher temperature in the cylinder, causing more time for nitrogen to react with oxygen, higher NO_x emissions. It is observed that fuel blend number 1 and 18 show lowest and highest NO_x emissions respectively which is in accordance with the published literature [Labeckas and Slavinskas 2006].

3.4 Combined effect of engine performance with emissions

From the engine performance analysis it is evident that the region of oxygen content from 1.8–3.0% provides the best engine performance wherein the BSEC for the fuel blends is in the minimum range as well the BTE in the maximum range. From the results of emission analysis, the CO, HC and smoke opacity trends satisfies this region as these emissions are continuously decreasing with increase in oxygen content. On the contrary, the results of NO_x and CO_2 emissions suggest the region of interest from 0.71% (lowest) up to 2.37%. Thus considering both the constraints – engine performance and emissions, the critical zone of interest in terms of oxygen content for each of the fuel types are evaluated and are shown in Fig. 3.The range of oxygen content in this critical zone is found to be 1.8–2.37%. The fuel blends within this critical zone, i.e. fuel blend nos. 8–13 show better engine performance on one hand and lower exhaust emissions on the other. The best suitable fuel blend in this range may be fuel blend number 13 composed of 2.37% oxygen, 84.88% carbon, and 12.56% hydrogen contents. Its chemical formula is evaluated to be with molecular weight 275.02 kg/kmol.

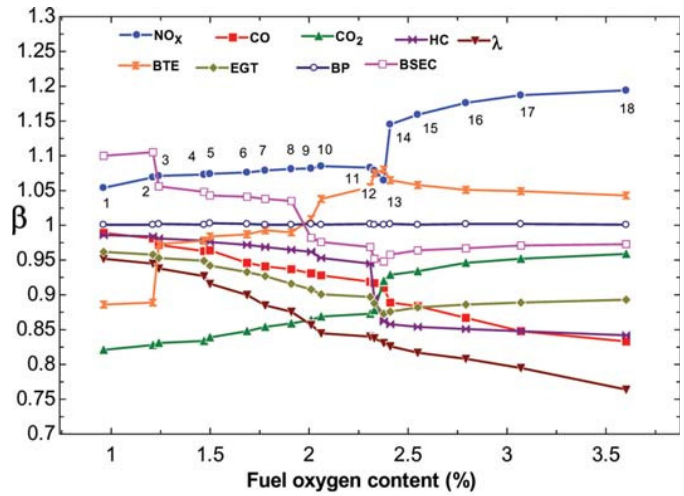


Fig. 4 Combined effect of $\beta_{\text{emission parameters}}$ and $\beta_{\text{engine performance parameters}}$ with fuel oxygen content

4. Conclusions

From the analysis of the obtained results it may be concluded that best engine performance i.e. lowest BSEC along with highest BTE is obtained for all the considered fuel blends when the fuel oxygen content lies between 1.8–3.0%.From the emission analysis at best performing loading condition, the CO, HC and smoke opacity trends are found to be decreasing with increase in oxygen content. Again, the NO_x and CO_2 emissions are on lower side in the range of oxygen content from 0.71% (lowest) up to 2.37%. Considering the importance of NO_x and CO_2 emissions, the suitable region of fuel oxygen content is found to be 0.71–2.37% for the selected fuel blends. Considering engine performance and emissions both, the critical zone of oxygen content is found to be 1.8–2.37%. The fuel blends within this critical zone, i.e. fuel blend nos. 8–13 show better engine performance along with lower emissions.

References

[1] Abd-Alla GH, Soliman HA, Badr OA, Abd-Rabbo MF, 2001, Effects of diluent admissions and intake air temperature in exhaust gas recirculation on the emissions of an indirect injection dual fuel engine, Energy Conversion and Management, 42, 1033–1045

[2] Atadashi IM, Aroua MK, Abdul Aziz A, 2010, High quality biodiesel and its diesel engine application: A review, Renewable and Sustainable Energy Reviews, 14, 1999–2008

[3] Babu AK, Devarajane G, 2003, Vegetable oils and their derivatives as fuels for CI engines: an overview, SAE Paper No. 2003-01-0767

[4] Canakci M, Sanli H, 2008, Biodiesel production from various feedstocks and their effects on the fuel properties,Journal of Industrial Microbiology & Biotechnology, 35, 431–441

[5] Demirbas A, 2007, Progress and recent trends in biofuels, Progress in Energy and Combustion Science, 33, 1–18

[6] Dhar A, Kevin R, Agarwal AK, 2012, Production of biodiesel from high-FFA neem

oil and its performance, emission and combustion characterization in a single cylinder DICI engine, Fuel Processing Technology, 97, 118–129

[7] Di Y, Cheung CS, Huang Z, 2009, Experimental investigation on regulated and unregulated emissions of a diesel engine fueled with ultra-low sulfur diesel fuel blended with biodiesel from waste cooking oil, Science of The Total Environment, 407, 835–846

[8] Dwivedi G, Sharma MP, 2013, Cold flow behaviour of biodiesel–A review, International Journal of Renewable Energy Research, 3, 827–836

[9] Ferella F, Mazziotti G, De Michelis I, Stanisci V, Veglio F, 2010, Optimization of the transesterification reaction in biodiesel production, Fuel, 89, 36–42

[10] Glaude PA, Fournet R, Bounaceur R, Molière M, 2010, Adiabatic flame temperature from biofuels and fossil fuels and derived effect on NO_x emissions, Fuel Processing Technology, 91, 229–235

[11] Hoekman SK, Robbins C, 2012, Review of the effects of biodiesel on NO_x emissions, Fuel Processing Technology, 96, 237–249

[12] Gumus M, Kasifoglu S, 2010, Performance and emission evaluation of a compression ignition engine using a biodiesel (apricot seed kernel oil methyl ester) and its blends with diesel fuel, Biomass and Bioenergy, 34,134–139

[13] Gumus M, Sayin C, Canakci M, 2012, The impact of fuel injection pressure on the exhaust emissions of a direct injection diesel engine fuelled with biodiesel-diesel fuel blends, Fuel, 95, 486–494

[14] Helwani Z, Othman MR, Aziz N, Fernando WJN, Kim J, 2009, Technologies for production of biodiesel focusing on green catalytic techniques: a review, Fuel Processing Technology, 90, 1502–1514

[15] Hoekman SK, Robbins C, 2012, Review of the effects of biodiesel on NO_xemissions, Fuel Processing Technology, 96, 237–245

[16] Joshi RM, Pegg MJ, 2007, Flow properties of biodiesel fuel blends at low temperatures, Fuel, 86, 143–151

[17] Kalam MA, Husnawan M, Masjuki HH, 2003, Exhaust emission and combustion evaluation of coconut-oil powered indirect injection diesel engine, Renewable Energy, 28, 2405–2415

[18] Kalligeros S, Zannikos F, Stournas S, Lois E, Anastopoulos G, Teas CH et al., 2003, An investigation of using biodiesel/marine diesel blends on the performance of a stationary diesel engine, Biomass and Bioenergy, 24, 141–149

[19] Karabektas M, 2009, The effects of turbocharger on the performance and exhaust emissions of a diesel engine fuelled with biodiesel, Renewable Energy, 34, 989–993

[20] Kumar MS, Ramesh A, Nagalingam B, 2003, An experimental comparison of methods to use methanol and jatropha oil in a compression ignition engine, Biomass and Bioenergy, 25,309–318

[21] Labeckas G, Slavinskas S, 2006, The effect of rapeseed oil methyl ester on direct injection diesel engine performance and exhaust emissions, Energy Conversion and Management, 47,1954–1967

[22] Manieniyan V, Sivaprakasam S, 2008, Investigation of diesel engine using bio-diesel (methyl ester of jatropha oil) for various injection timing and injection pressure, SAE Technical Paper 2008-01-1577

[23] Misra RD, Murthy MS, 2011, Performance, emission and combustion evaluation of soapnut oil–dieselblends in a compression ignition engine, Fuel, 90, 2514 2518

[24] Monyem A, Van Gerpen JH, Canakci M, 2001, The effect of timing and oxidation on emissions from biodiesel-fueled engines, Transactions ASAE, 44, 35–42

[25] Murugesan A, Umarani C, Subramanian R, Nedunchezhian N, 2009, Bio-diesel as an alternative fuel for diesel engines-a review, Renewable and Sustainable Energy Reviews,13, 653–662

[26] Nabi MN, Akhter MS, Shahadat MMZ, 2006, Improvement of engine emissions with conventional diesel fuel and diesel-biodiesel blends, Bioresource Technology, 97, 372–378

[27] Özener O, Yüksek L, Ergenç AT, Özkan M, 2014, Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics, Fuel, 115, 875–883

[28] Qi DH, Chen H, Geng LM, Bian YZH, 2010, Experimental studies on the combustion characteristics and performance of a direct injection engine fueled with biodiesel/diesel blends, Energy Conversion and Management, 51, 2985–2992

[29] Raheman H, Ghadge SV, 2007, Performance of compression ignition engine with mahua (Madhuca indica) biodiesel, Fuel, 86, 2568–2573

[30] Raheman H, Phadatare AG, 2004, Diesel engine emissions and performance from blends of karanja methyl ester and diesel, Biomass Bioenergy, 27, 393–397

[31] Ribeiro NM, Pinto AC, Quintella CM, Da Rocha GO, Teixeira LSG et al., 2007, The role of additives for diesel and diesel blended (ethanol or biodiesel) fuels: A review, Energy & Fuels, 21, 2433–2445

[32] Sahoo PK, Das LM, Babu MKG, Arora P, Singh VP, Kumar NR, Varyani TS, 2009, Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine, Fuel, 88, 1698–1707

[33] Sakthivel G, Llangkumaran M, Gaikwad A, 2015, A hybrid multi-criteria decision modeling approach for the best biodiesel blend selection base on ANP-TOPSIS analysis, Ain Shams Engineering Journal, 6, 239–256

[34] Sayin C, Gumus M, 2011, Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel, Applied Thermal Engineering, 31, 3182–3188

[35] Sendzikiene E, Makareviciene V, Janulis P, 2006, Influence of fuel oxygen content on diesel engine exhaust emissions, Renewable Energy, 31, 2505–2512

[36] Usta N, Öztürk E, Can Ö, Conkur ES, Nas S, Çon AH, Can AÇ, Topcu M, 2005, Combustion of biodiesel fuel produced from hazelnut soapstuck/waste sunflower oil mixture in a diesel engine, Energy Conversion and Management, 46, 741–755

[37] Xue J, Grift TE, Hansen AC, 2011, Effect of biodiesel on engine performances and emissions, Renewable and Sustainable Energy Reviews, 15, 1098–1116

[38] Yilmaz N, Vigil FM, Donaldson AB, Darabseh T, 2014, Investigation of CI engine emissions in biodiesel–ethanol–diesel blends as a function of ethanol concentration, Fuel, 115, 790–793