Environmental Science and Pollution Research (2023) 30:98848–98857
https://doi.org/10.1007/s11356-022-22039-3

ADVANCES IN SCIENCE, ENGINEERING AND TECHNOLOGY IN COMBATING POLLUTION FOR A SUSTAINABLE FUTURE

Influence of fuel injection timing and trade-off study on the RCCI engine characteristics of Jatropha oil-diesel blend under 1-pentanol dual-fuel strategies

Athmakuri Ashok[1] · Santhosh Kumar Gugulothu[1] · Ragireddy Venkat Reddy[2] · Bhasker Burra[3]

Received: 7 February 2022 / Accepted: 11 July 2022 / Published online: 20 July 2022

Abstract

The current study deals with a reactivity-controlled compression ignition (RCCI) engine working with 1-pentanol as the LRF and JOBD as the HRF. The composition of the pilot fuel includes 20% Jatropha oil and 80% diesel, which nearly matches the heating value and cetane index of petroleum diesel. The research focuses on studying the impact of the pilot fuel injection angle on the engine characteristics at full load conditions, and the pilot fuel injection angle varies from 19, 21, 23, 25, to 27° bTDC at a constant injection pressure of 600 bar. The results revealed that increasing the pilot fuel injection angle increased the engine performance with a 13.36% rise in BTE, a reduction in CO emissions by 11.03%, and a decrease in HC emissions by 9.28% at a pilot fuel injection angle of 25° bTDC at 30% pentanol energy share (BD70P30). On the other hand, NO_x emissions rise by 11.07%. The results indicate that the performance of the ternary fuelled RCCI engine can be improved by increasing the fuel injection angle of the pilot fuel.

Keywords RCCI · Ternary fuel · FIT · FIP · NO_x · Trade-off study

Introduction

In the last few decades, petroleum reserves around the globe have reached the stage of exhaustion in their severe form. Due to the improved thermal efficiencies, diesel-fuelled engines are used in transportation and industry nowadays. On the other hand, diesel-fuelled engines are responsible for producing toxic emissions like unburnt hydrocarbons (UHC) and carbon monoxide (CO) in large amounts (Madane et al. 2020; Bhowmik et al. 2019). COVID-19 pandemic has resulted in a global economic recession and a disturbance in stockpile regions. It was observed that fuel prices around the globe would remain inconsistent for the foreseeable future. The automobile industry is in dire need of finding efficient fuel/energy supply methods to aid the diesel engine power train, which is a very tough task. However, alternate biofuels that have the capability to fully replace diesel fuel in the CI engines are available, like bio-ethers, bio-alcohols, biodiesel, etc. (advanced biofuels) (Bhowmik et al. 2018a, b; Aydin and Ilkılıc 2010; Banapurmath and Tewari 2010; Sureshkumar et al. 2008; Chauhan et al. 2013). But there are many hurdles in the efficient usage of these advanced biofuels due to sample degradation, blend stability, miscibility problems, and physicochemical properties that need to be properly handled (Altin et al. 2001; Venkata Subbaiah and Raja Gopal 2011; Yesilyurt et al. 2018). In order to orient the physicochemical properties of biodiesel to those of traditional diesel fuel, a modern strategy was developed by many researchers by incorporating different types of additives into the fuel (Yesilyurt et al. 2018; Kolli et al. 2019; Venu and Madhavan 2017; Paul et al. 2015a, b, 2017).

Kolli et al. (2019) stated that when DEE (diethyl ether) was added to biodiesel, the engine's emission characteristics

---

Responsible Editor: Philippe Garrigues

✉ Santhosh Kumar Gugulothu
santoshgk1988@gmail.com

[1] Department of Mechanical Engineering, National Institute of Technology Andhra Pradesh, Andhra Pradesh, India

[2] Department of Mechanical Engineering, ANURAG University, Hyderabad, India

[3] Department of Mechanical Engineering, GITAM University, Hyderabad, India

became better due to the increase in viscosity, cetane number, and oxygen content of the fuel without disturbing engine performance. Venu and Madhavan (2017) stated that the cylinder pressure of the engine was improved by incorporating DEE in the diesel-ethanol-biodiesel blend. de Carvalho et al. (2020) revealed that NO_x emissions and BTE were improved by containing DEE and ethanol. Yesilyurt et al. (2020) demonstrated that inclusion of DEE reduced diesel engine smoke, UHC, and NO_x emissions in the biodiesel-diesel mix. It was observed that hydrocarbon and NO_x emissions were enhanced by using bio-based ethanol (Bhowmik et al. 2017, 2018a, b; Paul et al. 2018). Shi et al. (2006) found that when the biodiesel-diesel blend was mixed with ethanol, NO_x emissions showed a small increase while HC emissions decreased. The previous study (Paul et al. 2015a, b) also disclosed that the united impact of cetane enhancing and oxygenated additives helped improve the engine performance considerably and reduce harmful emissions from the engine. Many researchers use gaseous fuels due to the concern of producing more power from the CI engine and extreme greenhouse emissions from the engine. In this research, the experiments were conducted to compare the RCCI engine characteristics fuelled with jatropha oil-diesel blend under 1-pentanol dual-fuel strategies with variable injection timing at constant P_{inj}. The engine performance, brake thermal efficiency, brake power, and specific fuel consumption and engine emissions, CO_2, CO, NO_x, HC, and O_2 were measured and analysed.

Research setup and methodology

Experimental setup

All the experiments were performed on the test rig comprising a single-cylinder, four strokes, and water-cooled, gasoline-powered engine manufactured by Kirlosker (modified) and with various instruments and sensors to measure the engine characteristics. The technical specification of the conventional engine is provided in Table 1 and the schematics of engine setup is shown in Fig. 1.

Table 1 Technical specification of Kirloskar engine

Parameters	Dimensions
Make	Kirloskar Oil Engines Ltd
Cylinder bore diameter	87.5 (mm)
Piston stroke	110 (mm)
Cubic capacity	661 cc
Compression ratio	10:1
No. of cylinder	Single
Engine speed	Variable 1200–1800 RPM
Cooling mode	Water cooled
Power rating	7 HP

The whole test setup consists of a conventional engine, eddy current dynamometer, rotameter, water pump, data acquisition system (DAQ), and various sensors to measure the engine characteristics. DAQ consists of load indicator, air surge tank, RPM indicator, crank angle sensor, and load cells. All the parameters are controlled, and the results are extracted to the computer system through DAQ. The test rig helps to study the engine's various performance characteristics, which can be further analysed through comparative analysis at various operating conditions. The existing conventional engine setup was then modified to operate dual fuel mode. The existing air intake manifold allowed only air into the intake manifold. The engine's load was controlled and measured by an AG series eddy current dynamometer manufactured by Saj Test Plant Pvt. Ltd. The dynamometer load was measured through a strain gauge load cell, and speed was measured from a shaft mounted with a rotary encoder. The engine and dynamometer require liquid cooling. Hence, the required rate of water through the calorimeter and engine was necessary to ensure optimum operating temperature. In the experimental setup, the rotameter was used to measure the flow rate of water. It works on the principle of variable area meter, which works on the buoyancy force principle, i.e. upthrust force and the float's weight, i.e. the force of gravity. The engine's rotameter water flow was set at 100 L per hour (lph), and calorimeter water flows at 250 lph as per requirement. The DAQ system helps extract data to the computer system and analyse various parameters with graphical representation. The DAQ system also consists of various sensors to analyse the engine parameters. These include the piezoelectric sensors, engine/calorimeter inlet temperature sensor, engine/calorimeter outlet temperature sensor, engine exhaust temperature sensor, and load cell sensor and differential air pressure transducers. The AVL engineering-made gas analyser (AVL DIGAS 444) was used in the experiment to measure the emissions. A gas analyser was used to measure the quantity of CO, NO_x, CO_2, and HC in the exhaust gases depending upon the working conditions. Exhaust gas was analysed for engine RPM and constant load operating conditions.

The uncertainty involved and the make of the instruments are as mentioned in Table 2 and the overall percentage of uncertainty was observed to be ± 1.3% as evaluated using Eq. (1).

$$\sqrt{(\mathrm{BTE}^2 + \mathrm{Volumetric\ Efficiency}^2 + \mathrm{EGT}^2 + \mathrm{CO}^2 + \mathrm{HC}^2 + \mathrm{NOx}^2 + \mathrm{Smoke}^2))} \tag{1}$$

Fuel blends used for engine operation

As mentioned below in Table 3, the quantity of fuel required for the various engine RPM was controlled/regulated through open engine control unit (ECU). The open ECU allows the user to control the fuel flow to the engine. The engine was tuned for fuel flow for the specific engine RPM mentioned below. At first, the engine was operated on the 100% conventional (petrol) fuel and then run on the mentioned fuel blends. In the experiment's third and fourth phases, the engine was operated with dual fuel, i.e. LRF and HRF.

Results and discussion

Engine combustion analysis

Figure 2(a–e) represents the variation of in-cylinder pressure and HRR against crank angle for different fuel injection angles at constant injection pressure of 600 bar. As Jatropha oil has a higher cetane number (CN) than pure diesel, it has a shorter ignition delay and, as a consequence, the fuel mixture has a significant improvement in combustion. All operations with ternary fuel with an injection angle greater than 23° bTDC resulted in an increase

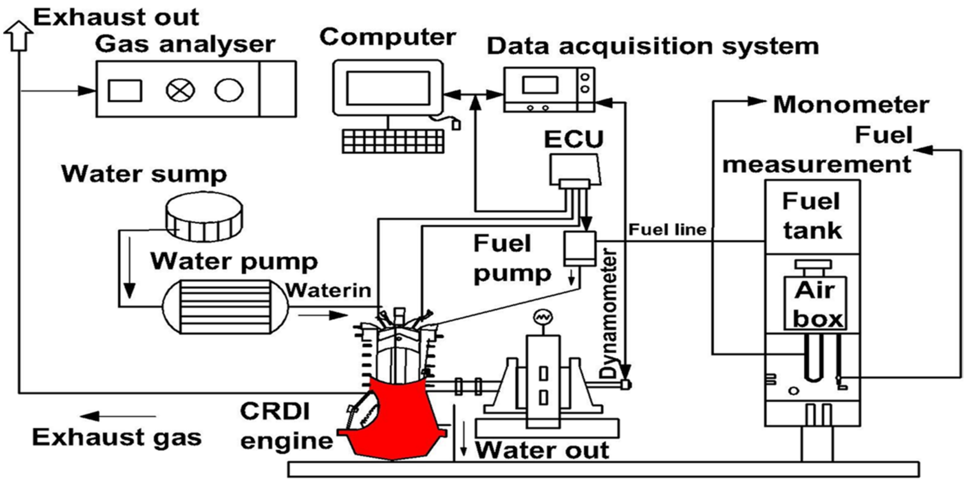

Fig. 1 Block diagram of the experimental setup

Table 2 Uncertainty analysis of instruments used in experiments

Equipment	Make	Range	Accuracy	Uncertainty (%)
Gas analyzer	AVL	CO: 0–10% HC: 0–20,000 ppm NOx: 0–5000 ppm	±0.01 ±1 ppm ±1 ppm	±0.5 ±0.7 ±0.3
Crank angle sensor	Kubler	0–360°	±1° CA	±0.2
Load cell	Sensortronics	0–50 kg	±0.1 kg	±0.1
Load indicator	ABUS Technologies	0–100 kg	±0.2%	±0.2
RPM indicator with Speed sensor	Selection process control	4–9999 rpm	±0.05%	±2.0
pressure transducer	PCB Piezotronics	5000 psi	±0.1 psi	±0.2

Table 3 Fuel/fuel blends used at variable engine RPM

Properties	Fuel blends					
	Density at 20 °C (kg/m^3)	Viscosity at 40 °C (cSt)	Cetane number	Calorific value (MJ/kg)	Water content (ppm)	Flash point (°C)
D100	831	2.223	50	43.168	13	60
Jatropha oil	878	5.01	51.1	39.69	14	168
1-Pentanol	816.9	2.96	19.12	35.56	16	54
BD90P10	836.42	2.81	52.48	41.96	89	59
BD80P20	841.23	2.69	49.98	41.48	159	44
BD70P30	833.42	2.89	49.23	39.96	269	40

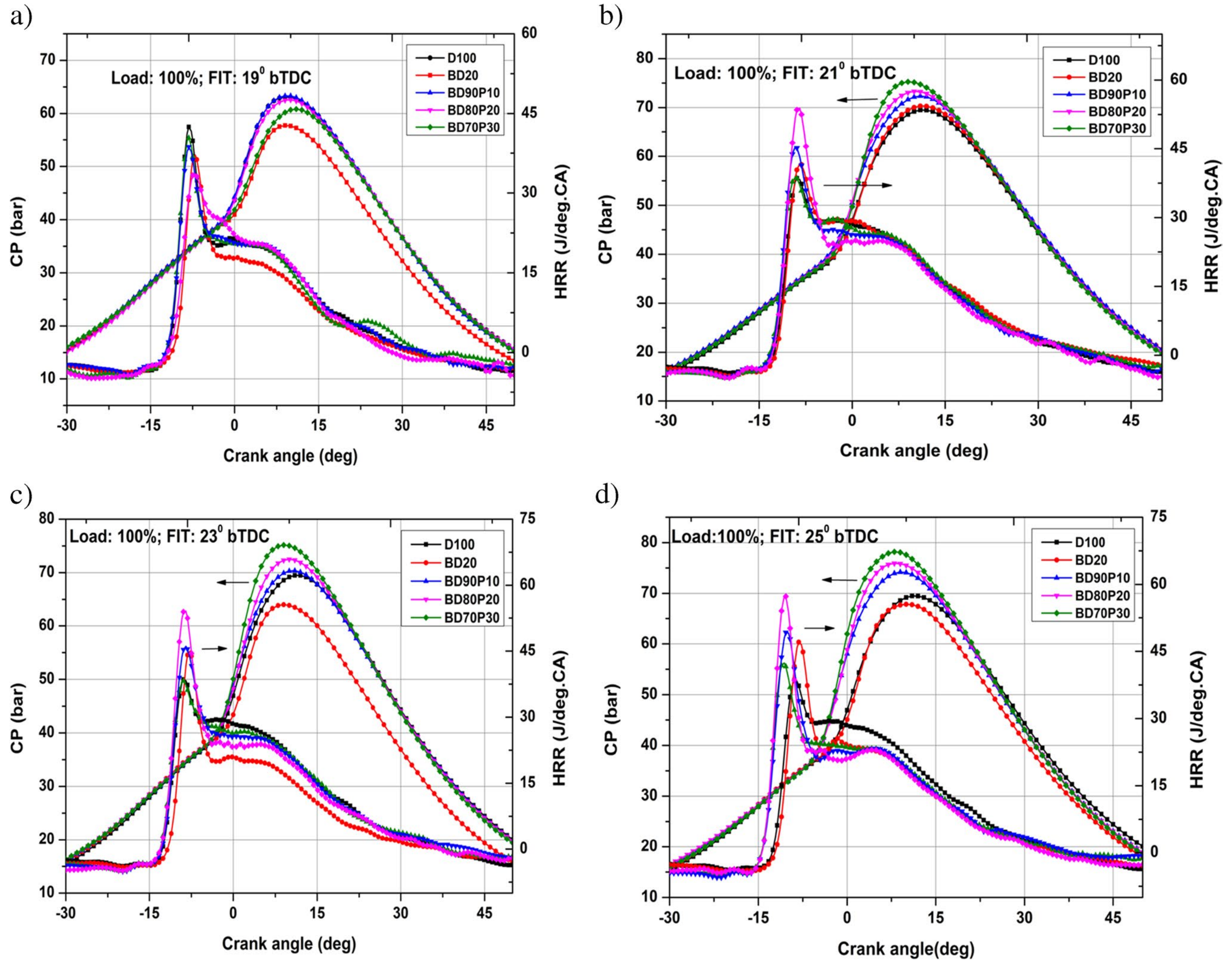

Fig. 2 CP and HRR variation against crank angle for different FIT at full load

in cylinder pressure, indicating improved combustion with biodiesel as a high reactivity fuel. According to some recent experimental studies, using 1-pentano1-diesel dual fuel results in a reduction in combustion quality, which contradicts the previous statement (Juknelevicius et al. 2019; Subramanian and Thangavel 2020; Sharma and Dhar 2019). It was discovered that a higher percentage of 1-pentanol can be included in biodiesel-based pilot fuels for the combustion process, and it was also discovered that as the 1-pentanol concentration increased, the cylinder pressure increased accordingly for each injection advancement. The reason behind this increase is the fact that there is enough time for proper mixing of compressed air and charge (due to the advancement of FIT) to form an appropriate mixture for combustion (Damodharan et al. 2018). Also, the combustion process is accelerated by the release of OH radicals and active oxygen from oxygen-rich compounds of the high reactive fuel. Figure 2(a–e) denotes the enhanced burning of fuel which resulted in high HRR and in-cylinder pressure. Even though at 27° bTDC injection, the cylinder pressure was quite high, the power output of the engine was reduced, resulting in less BTE. This reduction is due to the excessive advancement of FIT, resulting in the formation of maximum pressure before the top dead centre (Fig. 2e) during the upward movement of the piston. Also, the combustion was thrust beyond the top dead centre when the piston had just started to move towards the bottom dead centre during decelerated injections. As a result, the total power output and efficiency of the engine were reduced. When the fraction of 1-pentanol in the fuel blend increases, the temperature within the cylinder rises owing to improved combustion. The fluctuation of maximum cylinder pressure against FIT for full load with various fuel mixes is depicted in Fig. 2(f). In comparison to other fuel mixes, the BD70P30 blend has the highest cylinder pressure (81.2 bar) at all FITs.

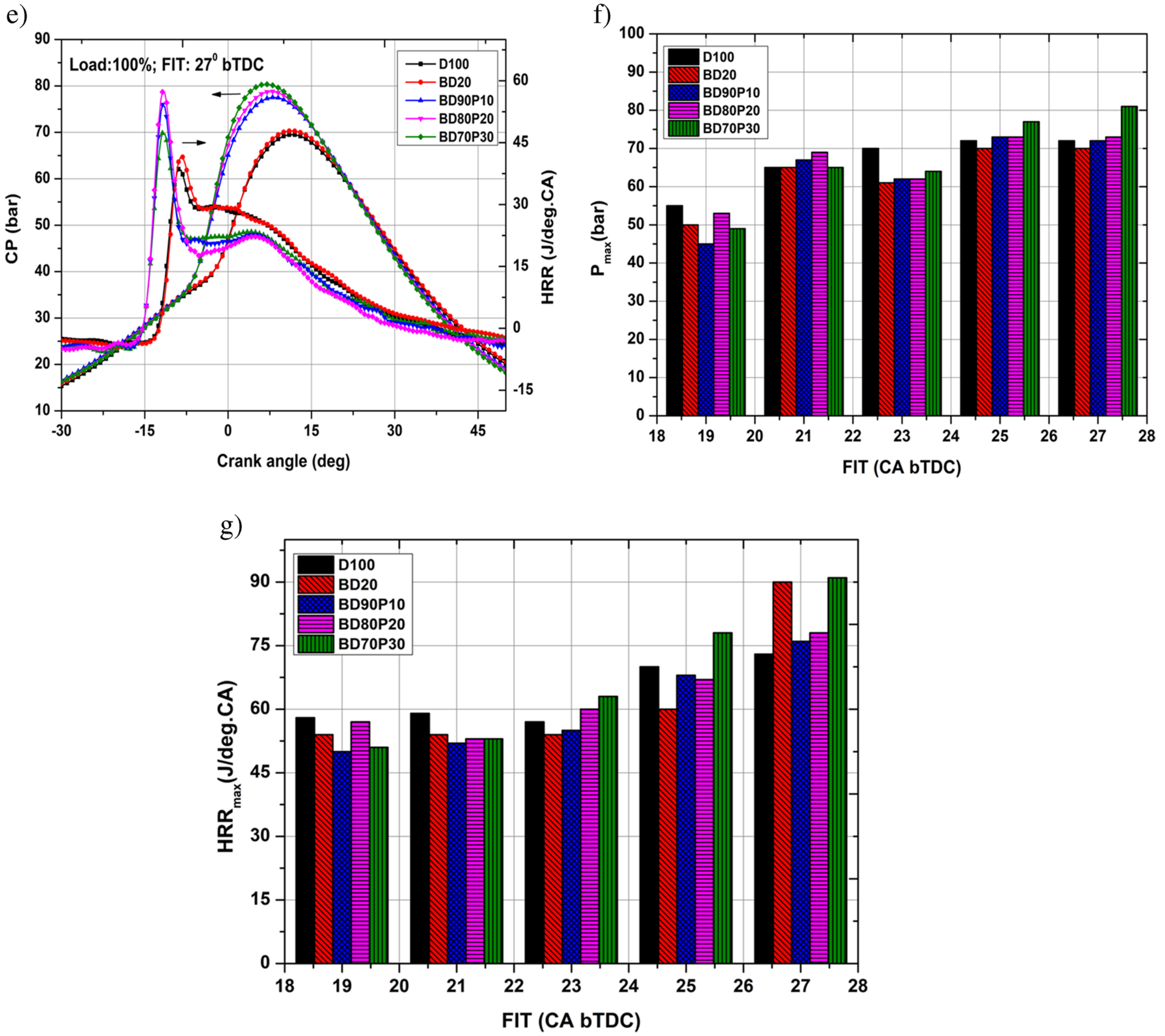

Fig. 2 (continued)

To estimate HRR manually, a mathematical model was used on the basis of cylinder pressure. Figure 2(a–e) shows the change in heat release rate with the rotation of the crank at various angles of injection for every test fuel and the peak HRR at various FIT. The HRR of the RCCI engine was enhanced with the advancement of the pilot fuel injection angle. This improvement in HRR occurs due to the improved conversion of fuel energy to heat energy, resulting in increased in-cylinder pressure (Fig. 2(a–e)), which in turn results in better combustion. It was also noted that at advanced pilot fuel injection angles, HRR increased due to the high 1-pentanol concentration in the pilot fuel. The development of a homogenous fuel–air blend was made possible due to the advancement in pilot fuel injection timings, which provided ample time for the mix formulation. The combustion process was found to be rapid due to the higher flame propagation facilitated by high octane 1-pentanol in the combustion chamber and the high cetane additive Jatropha oil in the pilot fuel, which facilitated the ignition of the charge and high heat release rates. Along with this, the OH radicals and active oxygen released during the separation of pilot fuel also helped in the enhancement of the combustion process (Sukjit et al. 2013). The reduction in HRR in ternary fuel work was also induced by the delay of the pilot injection angle, as the piston's HRRs and in-cylinder pressures are lower at late injection because the piston has just started moving swiftly away from the top dead centre. The fluctuation of maximum HRR against FIT for full load with various fuel mixes is depicted in Fig. 2(g). In comparison to other fuel mixes, the BD70P30 blend has the highest HRR cylinder pressure (91.2 J/deg.CA) at all FITs.

Ignition delay

The ignition delay is the most important metric in the research of internal combustion engines (ID). “Ignition delay” refers to the time between the SOI and the SOC. Ignition delay is influenced by cylinder temperature as well as fuel qualities such as CN. Figure 3 depicts the ignition delay for various fuel mixtures at different FIT at full load. Because JOBD has a high CN, the ID for diesel at each injection timing was shown to be more significant than for biodiesel blends. It is observed that with an increase in the 1-pentanol share ignition delay also increased at 19 and 21° bTDC. Because the injection start angles for each method were consistent, the time it took for the 1-pentanol-enriched charge to reach the ignition point increased as the pilot fuel was injected closer to TDC. This pattern is especially relevant for high hydrogen inputs. After 23° bTDC, the pilot fuel has enough time to reach ignition temperature and start the 1-pentanol-rich charge combustion (Zhou et al. 2014).

Combustion duration

The combustion duration of the engine for each test fuel combo is depicted in Fig. 4. It was clear from the graph that as the pilot fuel injection angle advancement rises, the combustion duration of the engine decreased due to the burning of more fuel in the premix stage (due to a decrease in ignition delay). Figure 2(a–e) depicts the relationship between HRR and pilot fuel injection advancement, and it was observed that HRR was sharper. For every pilot fuel injection advancement, as 1-pentanol concentration increases, the combustion duration also rises accordingly, denoting a slowdown in combustion phenomena. It is also observed that with an advancement in injection timing, cylinder pressure was found to be smoother with injection advancement, denoting constant combustion.

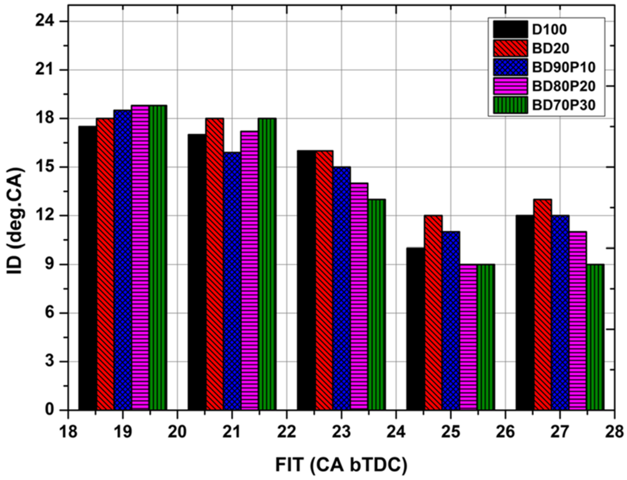

Fig. 3 ID against FIT for different fuel blends at full load

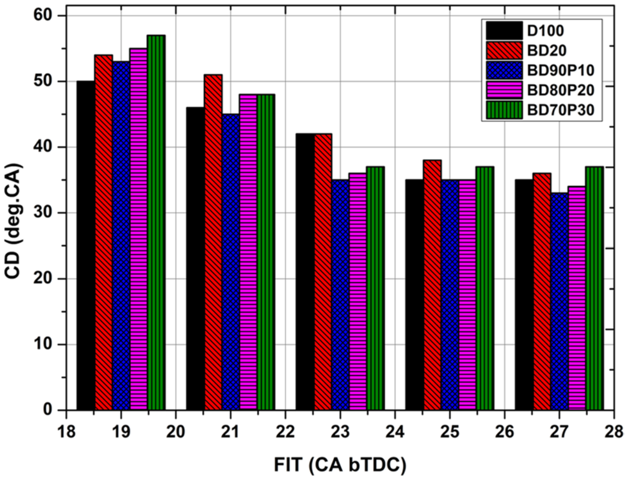

Fig. 4 Combustion duration against FIT for different fuel blends at full load

Engine performance analysis

Figure 5 shows a small reduction in BTE for all fuel injection strategies of the ternary fuel in comparison to an engine operating with traditional diesel fuel. The fuel used for the test has a high viscosity and a slightly lower calorific value, so the quantity of heat released inside the combustion chamber of the engine was less, which led to a low value of maximum in-cylinder pressure (Bhale et al. 2009). The BTE of the RCCI engine was enhanced due to

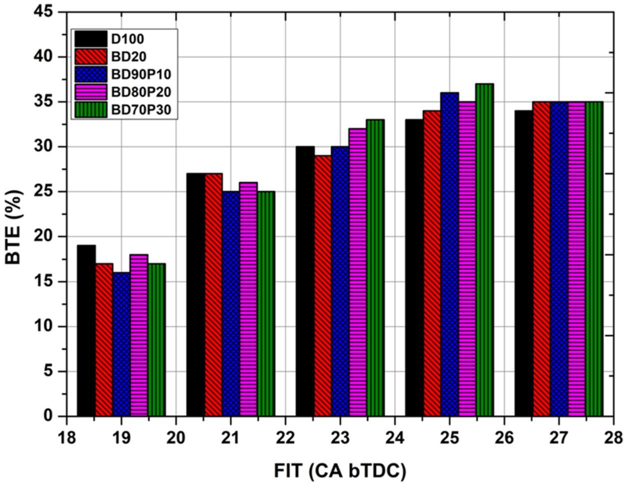

Fig. 5 BTE against FIT for different fuel blends at full load

the increase in calorific value of the cumulative charge due to the direct injection of 1-pentanol through inlet manifold into the engine. The traditional diesel fuel working at 25° bTDC of fuel injection timing was compared with various ternary fuel blends and it was revealed that the BD70P30 blend achieved 9.25% more brake thermal efficiency, as compared to B20 operation, and this was 4.03% more than the brake thermal efficiency of diesel. As the FIT of test fuels was increased, brake thermal efficiency also increased accordingly. It was observed that the test fuels got ample time to achieve the maximum in-cylinder pressure closer to the top dead centre when the FIT was found to be advanced (Agarwal et al. 2013). The brake thermal efficiency at FIT of 27° bTDC was seen to decrease due to interference between the in-cylinder pressure and the compression pressure caused by too much FIT advancement. The peak cylinder pressure at 27° bTDC came significantly earlier than the 25° bTDC injection angle, as seen in Fig. 2(d, e).

Figure 6 shows the variation of BSEC for the test fuels. Improved air–fuel mixing resulted in complete combustion and a liberation peak heat closer to TDC (Fig. 2a–e). A better mix of fuel and air has led to a decrease in ternary fuel as fuel injection timing advances. It was observed that due to excess build-up of fuel, the BSEC of the test fuels at 27° bTDC was found to be increasing. For all FIT, more BSEC was obtained for the BD20 fuel owing to the lower calorific value of the BD20 blend when compared to working with diesel fuel. But the BSEC of the engine was decreased when 1-pentanol fuel was used instead of the BD20 blend, which was more important at advanced FIT. BSEC of the engine was increased due to the greater energy share of 1-pentanol fuel. When compared to diesel fuel and BD20 operation at 25° bTDC, the BSEC of BD70P30 shows an enhancement of 3.87% and 8.46%, respectively.

Engine emission analysis

Figure 7 illustrates the $BSNO_x$ emissions against FIT. Compared to traditional diesel fuel, the $BSNO_x$ emissions of BED mix fuel were found to be lower for all FIT. The major factors behind these reduced emissions are the reduction in NO_x formation and in-cylinder temperature (Paul et al. 2015a, b), which were due to the huge cooling effect formed by the evaporation of biodiesel additives. Whereas, incorporating 1-pentanol in dual fuel modes resulted in an increase in in-cylinder temperature and nitric oxide emissions due to the liberation of the huge amount of heat during combustion, due to the high calorific value of 1-pentanol. As FIT increased, an upward trend was observed for the $BSNO_x$ emissions. It was found that test fuels are developing higher HRR nearer to the top dead centre due to advancements in FIT while the nominal volume of the combustion chamber is small. As a result, NO_x formation was increased due to an increase in in-cylinder temperature and the formation of a favourable condition for the reaction of nitrogen and hydrogen molecules (Subramanian and Thangavel 2020). As shown in Fig. 3(a–e), it can be concluded that as the pilot fuel injection advances, the test fuels release higher HRR.

Figure 8 illustrates the BSHC emissions against FIT. Also, it is observed that BD20 blend showed marginally higher HC emission than pure diesel. The addition of 1-pentanol generates a cooling effect which results in higher BSHC emissions with the BD20 blend. The temperature decreases inside the cylinder through evaporation phenomena, and hence the BSHC rises. In addition, it is observed that the addition of 1-pentanol fuel significantly reduces BSHC emissions from the engine. At 21° bTDC fuel injection timing, the BD70P20 improved by 25.14% over pure diesel and 27.03% in comparison with BD20, respectively. Hydrocarbon content in the test fuels was reduced, which

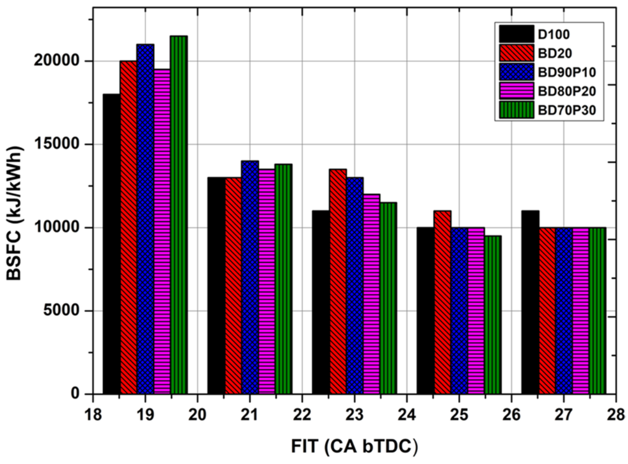

Fig. 6 BSEC against FIT for different fuel blends at full load

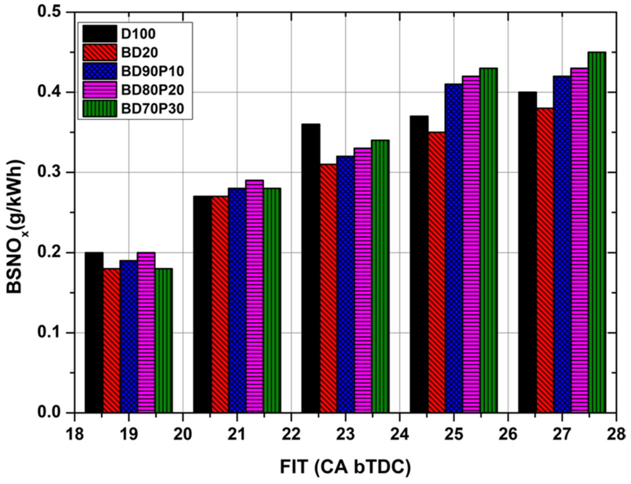

Fig. 7 $BSNO_x$ against FIT for different fuel blends at full load

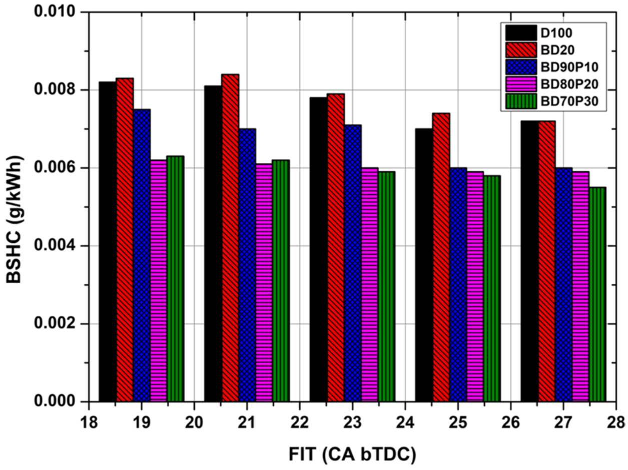

Fig. 8 BSHC against FIT for different fuel blends at full load

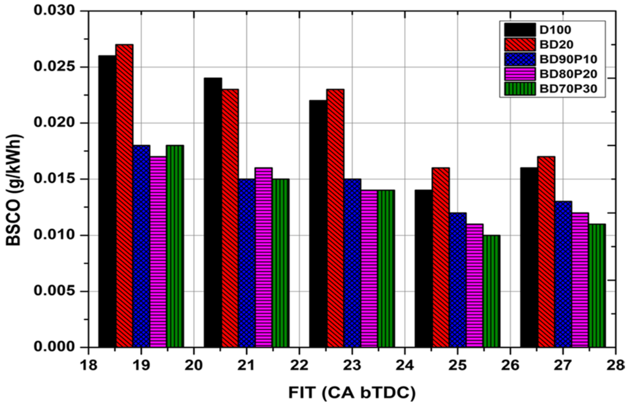

Fig. 9 BSHC against FIT for different fuel blends at full load

resulted in lower BSHC emissions for dual fuel operations. The engine's BSHC emissions were also lowered as a result of the progress in fuel injection timing. As a result, HC emissions were reduced as the dissociation of the oxygenated additive 1-pentanol was enhanced, resulting in larger concentrations of the reactive "O" and "OH" radicals. The improvement in the premixed regions' burning rate resulted in a greater in-cylinder temperature.

Figure 9 illustrates the BSCO emissions against FIT. The BD20 blend was found to have a higher brake-specific carbon monoxide (BSCO) emission at nearly all injection timings. For all injection timings, 1-pentanol/BD20 dual fuel strategies showed a significant reduction in BSCO emissions compared to diesel and BD20. At 21° bTDC FIT, the BD70P20 strategy reduced emissions by 36.64% compared to pure diesel and 35.76% compared to BD20 blend. The reduction in the total carbon content of the fuels is responsible for the improvement in CO emission levels. The BSCO showed a steadily declining pattern as the FIT was increased in the mixture. As a result of the overall improvement in combustion, higher cylinder temperatures were achieved, resulting in reduced CO emissions, through a complete conversion of CO to CO_2 (El-Seesy et al. 2017; Yesilyurt and Aydin 2020).

Conclusion

The current study deals with a RCCI engine working with 1-pentanol as the LRF and JOBD as the HRF. The composition of the pilot fuel includes 20% Jatropha oil and 80% diesel, which nearly matches the heating value and cetane index of petroleum diesel. The research focusses on studying the impact of the pilot fuel injection angle on the engine characteristics at full load conditions, and the pilot fuel injection angle varies from 19, 21, 23, 25, to 27° bTDC at a constant injection pressure of 600 bar.

- All operations with ternary fuel with an injection angle greater than 23° bTDC resulted in an increase in cylinder pressure, indicating improved combustion with biodiesel as a high reactivity fuel.
- At 27° bTDC injection, the cylinder pressure was quite high, the power output of the engine was reduced, resulting in less BTE. This reduction is due to the excessive advancement of FIT, resulting in the formation of maximum pressure before the top dead centre during the upward movement of the piston.
- The combustion process was found to be rapid due to the higher flame propagation facilitated by high octane 1-pentanol in the combustion chamber and the high cetane additive Jatropha oil in the pilot fuel, which facilitated the ignition of the charge and high heat release rates.
- It is observed that with an increase in the 1-pentanol share ignition delay also increased at 19 and 21° bTDC. Because the injection start angles for each hydrogen method were consistent, the time it took for the 1-pentanol-enriched charge to reach the ignition point increased as the pilot fuel was injected closer to TDC.
- The traditional diesel fuel working at 25° bTDC of fuel injection timing was compared with various ternary fuel blends and it was revealed that the BD70P30 blend achieved 9.25% more brake thermal efficiency, as compared to B20 operation, and this was 4.03% more than the brake thermal efficiency of diesel.
- As FIT increased, an upward trend was observed for the $BSNO_x$ emissions. It was found that test fuels are developing higher HRR nearer to the top dead centre due to advancements in FIT while the nominal volume of the combustion chamber is small.
- The addition of 1-pentanol generates a cooling effect which results in higher BSHC emissions with the BD20 blend.

The temperature decreases inside the cylinder through evaporation phenomena, and hence the BSHC rises.

- For all injection timings, 1-pentanol/BD20 dual fuel strategies showed a significant reduction in BSCO emissions compared to diesel and BD20. At 21° bTDC FIT, the BD70P20 strategy reduced emissions by 36.64% compared to pure diesel and 35.76% compared to BD20 blend.

Author contribution Santhosh Kumar Gugulothu: conceptualization; procedure; writing, review, and editing; and supervision. Athmakuri Ashok: experimental analysis, procedure, and writing. Ragireddy Venkat Reddy: supervision. Bhasker Burra: analysis exploration and documentation.

Data availability The data acquired or analyzed during this investigation are incorporated in this article.

Declarations

Ethics approval and consent to participate The simulation analysis was not harmed any human or animal. National and international guidelines are followed for the protection of social welfare.

Consent for publication We affirm that the article has been studied and accepted by all listed authors. In addition, we affirm that all the authors mentioned in the article have been approved by all of us.

Competing interests The authors declare no competing interests.

References

Agarwal AK, Srivastava DK, Dhar A, Maurya RK, Shukla PC, Singh AP (2013) Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine. Fuel 111:374–383

Altın R, Cetinkaya S, Yücesu HS (2001) The potential of using vegetable oil fuels as fuel for diesel engines. Energy Convers Manage 42(5):529–538

Aydin H, Ilkılıc C (2010) Effect of ethanol blending with biodiesel on engine performance and exhaust emissions in a CI engine. Appl Therm Eng 30(10):1199–1204

Banapurmath NR, Tewari PG (2010) Performance, combustion, and emissions characteristics of a single-cylinder compression ignition engine operated on ethanol—biodiesel blended fuels. Proc Inst Mech Eng Part A: J Power Energy 224(4):533–543

Bhale PV, Deshpande NV, Thombre SB (2009) Improving the low temperature properties of biodiesel fuel. Renewable Energy 34(3):794–800

Bhowmik S, Paul A, Panua R, Ghosh SK, Debroy D (2019) Artificial intelligence based gene expression programming (GEP) model prediction of diesel engine performances and exhaust emissions under Diesosenol fuel strategies. Fuel 235:317–325

Bhowmik S, Panua R, Debroy D, Paul A (2017) Artificial neural network prediction of diesel engine performance and emission fueled with diesel–kerosene–ethanol blends: a fuzzy-based optimization. J Energy Resour Technol 139(4):042201

Bhowmik S, Panua R, Kumar Ghosh S, Debroy D, Paul A (2018a) A comparative study of artificial intelligence based models to predict performance and emission characteristics of a single cylinder diesel engine fueled with diesosenol. J Thermal Sci Eng Appl 10(4)

Bhowmik S, Paul A, Panua R, Ghosh SK, Debroy D (2018b) Performance-exhaust emission prediction of diesosenol fueled diesel engine: an ANN coupled MORSM based optimization. Energy 153:212–222

Chauhan BS, Kumar N, Cho HM, Lim HC (2013) A study on the performance and emission of a diesel engine fueled with Karanja biodiesel and its blends. Energy 56:1–7

Damodharan D, Sathiyagnanam AP, Rana D, Kumar BR, Saravanan S (2018) Combined influence of injection timing and EGR on combustion, performance and emissions of DI diesel engine fueled with neat waste plastic oil. Energy Convers Manage 161:294–305

de Carvalho MA, Achy AR, Junior LC, Ferreira VP, da Silva JA, Pepe IM, Torres EA (2020) Mechanical and emissions performance of a diesel engine fueled with biodiesel, ethanol and diethyl ether blends. J Braz Soc Mech Sci Eng 42(4):1–10

El-Seesy AI, Abdel-Rahman AK, Bady M, Ookawara SJEC (2017) Performance, combustion, and emission characteristics of a diesel engine fueled by biodiesel-diesel mixtures with multi-walled carbon nanotubes additives. Energy Convers Manage 135:373–393

Jukenevičius R, Rimkus A, Pukalskas S, Matijošius J (2019) Research of performance and emission indicators of the compression-ignition engine powered by hydrogen-diesel mixtures. Int J Hydrogen Energy 44(20):10129–10138

Kolli VK, Gadepalli S, Barma JD, Maddali MK, Barathula S, reddySiddavatam N K (2019) Establishment of lower exhaust emissions by using EGR coupled low heat loss diesel engine with fuel blends of microalgae biodiesel-oxygenated additive DEE-antioxidant DPPD. Thermal Science and Engineering Progress 13:100401

Madane PA, Bhowmik S, Panua R (2020) Hybrid Taguchi–fuzzy-based performance-exhaust emission trade-off study of variable compression ratio diesel engine fueled with undi-diesel blends. Environ Prog Sustainable Energy 39(2):e13333

Paul A, Bose PK, Panua R, Debroy D (2015a) Study of performance and emission characteristics of a single cylinder CI engine using diethyl ether and ethanol blends. J Energy Inst 88(1):1–10

Paul A, Panua R, Bose PK (2015b) Effect of diesel–ethanol–PPME (Pongamia pinata methyl ester) blends as pilot fuel on CNG dual-fuel operation of a CI engine: A performance-emission trade-off study. Energy Fuels 29(4):2394–2407

Paul A, Panua R, Debroy D (2017) An experimental study of combustion, performance, exergy and emission characteristics of a CI engine fueled by diesel-ethanol-biodiesel blends. Energy 141:839–852

Paul A, Bhowmik S, Panua R, Debroy D (2018) Artificial neural network-based prediction of performances-exhaust emissions of diesohol piloted dual fuel diesel engine under varying compressed natural gas flowrates. J Energy Resour Technol 140(11)

Sharma P, Dhar A (2019) Effect of hydrogen fumigation on combustion stability and unregulated emissions in a diesel fuelled compression ignition engine. Appl Energy 253:113620

Shi X, Pang X, Mu Y, He H, Shuai S, Wang J, Chen H, Li R (2006) Emission reduction potential of using ethanol–biodiesel–diesel fuel blend on a heavy-duty diesel engine. Atmos Environ 40(14):2567–2574

Subramanian B, Thangavel V (2020) Experimental investigations on performance, emission and combustion characteristics of diesel-hydrogen and diesel-HHO gas in a dual fuel CI engine. Int J Hydrogen Energy 45(46):25479–25492

Sukjit E, Herreros JM, Dearn KD, Tsolakis A, Theinnoi K (2013) Effect of hydrogen on butanol–biodiesel blends in compression ignition engines. Int J Hydrogen Energy 38(3):1624–1635

Sureshkumar K, Velraj R, Ganesan R (2008) Performance and exhaust emission characteristics of a CI engine fueled with Pongamia pinnata methyl ester (PPME) and its blends with diesel. Renewable Energy 33(10):2294–2302

Venkata Subbaiah G, Raja Gopal K (2011) An experimental investigation on the performance and emission characteristics of a diesel engine fuelled with rice bran biodiesel and ethanol blends. Int J Green Energy 8(2):197–208

Venu H, Madhavan V (2017) Influence of diethyl ether (DEE) addition in ethanol-biodiesel-diesel (EBD) and methanol-biodiesel-diesel (MBD) blends in a diesel engine. Fuel 189:377–390

Yesilyurt MK, Aydin M (2020) Experimental investigation on the performance, combustion and exhaust emission characteristics of a compression-ignition engine fueled with cottonseed oil biodiesel/diethyl ether/diesel fuel blends. Energy Convers Manage 205:112355

Yeşilyurt M, Arslan M, Eryilmaz T (2018) Experimental investigation of the effects of ethanol addition into biodiesel-diesel fuel blends on the performance, combustion and emission characteristics. Isi Bilimi Ve Teknigi Dergisi-J Thermal Sci Technol 38(2).

Yesilyurt MK, Cesur C, Aslan V, Yilbasi Z (2020) The production of biodiesel from safflower (Carthamus tinctorius L.) oil as a potential feedstock and its usage in compression ignition engine: a comprehensive review. Renew Sustain Energy Rev 119:109574

Zhou JH, Cheung CS, Leung CW (2014) Combustion, performance and emissions of a diesel engine with H2, CH4 and H2–CH4 addition. Int J Hydrogen Energy 39(9):4611–4621