IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Performance, Combustion And Emission Characteristics Of Diesel Engine In Different Modes Run On Alternate Fuels - A Review

Sardar M. Shaikh[1*], S. V. Khandal[2]

[1,2] Department Mechanical Engineering, Sanjay Ghodawat University, Kolhapur, Maharashtra, India

Abstract:

Now a days the CI engines becomes very popular because of its wide applications in all sectors. But at the same time they produce the emissions which are harmful for human being. It is not able to meet the demands of compression ignition (CI) engines for greater fuel economy and reduced exhaust gas emissions with mechanically controlled fuel injection systems alone. The electronically controlled fuel injection system (ECU), which forms the core of a CI engine, has emerged as a crucial control technology in recent times. The common rail direct injection (CRDI) method lowers emissions while also increasing the brake thermal efficiency (BTE). Biodiesels are very good alternative to replace fossil fuel due to their distinct properties towards control emissions and availability. Another alternative fuel known as clean fuel is hydrogen, which burns with zero emissions. Researchers worldwide working seriously to explore dual fuel (DF) application for diesel engines with better fuel injection techniques that reduce harmful effects besides conserving diesel. Thus, it is necessary to talk about the operation, emissions, and combustion of CI, CRDI and DF engines that are powered by alternative fuels. This study provides a thorough analysis of the same.

Keywords: Compression Ignition (CI) Engine; Common Rail Direct Injection (CRDI) Engines; Performance; Emission

1. Introduction

In vast application, compression ignition (CI) engines are used due to their versatile nature and more power output. Internal combustion (IC) engines design concepts and sustainable developments are drastically changing due to the strict pollution regulations. It is anticipated that the development process focus on IC engine combustion with use of the compatible fuels in various combustion modes. The effective exhaust gas after treatment and the application of substitute materials are additional considerations to be taken into account to save environment besides their conservation.

So the global dedicated team of scientists independently or in team carrying out in-depth studies to find fuel substitutes to run IC engines that save environment. Biodiesels have oxygen content of about 9–12% which help in complete combustion [01]. Emission treatment systems and engine design must be economical and efficient in order to comply with emission regulations. For which understanding of the combustion process in IC engines is essential [02]. Engine performance, exhaust emissions study was carried out on diesel engine and it is reported that the brake power (BP) with JME was higher than the neat diesel but oxides of nitrogen (NOx) emission was higher with JME than diesel at different conditions besides increase in fuel economy with the reduction in NOx emissions was obtained at exhaust gas recirculation (EGR) rate of 5% [03]. The investigation of the impacts of n-butanol addition into waste tire oil - diesel blend on engine performance in a single-cylinder CI was carried out. Brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) values have been slightly improved with the increasing ratio of n-butanol due to the high oxygen content and laminar flame rate in the mixture with n-butanol content thereof. Ternary blends containing neat diesel, n-butanol, and waste tire oil can be alternatively used in a diesel engine without any engine modification [04]. The CI engine run with biodiesels of flax, cotton seed and palm oil yielded less BP, higher BSFC, lower carbon monoxide (CO) and smoke emissions with slight increase in NOx emissions. It is reported that NOx decreased with higher CO when EGR was used. The peak cylinder gas pressure (PP) for all biodiesel operation was higher compared to neat diesel operation [05]. The Common rail direct injection (CRDI) engine has triggered new technological innovations and made large contribution in reduction of exhaust emission, fuel consumption with better performance and smooth working. This is because of increased injection pressure (IP), better atomization, uniformity of fuel mixture and high accurate control of small quantity injection [06]. Hydrogen-powered IC engines with near-zero emissions and higher BTE than diesel engines is an attractive solution and also takes significant advantage of the mature IC engine design. The necessary modifications related to the use of hydrogen as a fuel concern the engine subsystems and components [07].

1.1 Biodiesel used in CI Engines

Even though more than 350 oil-bearing crops are available on earth, only few are potential to replace diesel as they have similar combustion characteristics as diesel and found that the base catalyst performs better than acid catalyst and enzymes. It is also inferred that the engine performance was inferior with vegetable oil / diesel blend as the high viscous oil caused injector choking and contaminated the lubricating oil. The tests with refined oil blends indicated considerable improvement in performance. The emission of unburnt hydrocarbon (HC) and NOx from the engine was found more with all the fuel blends as compared to diesel [08]. The investigations using the blending method, n-butanol, a potentially promising biofuel, can be used safely in a real turbocharged automotive diesel engine. The addition of n-butanol to diesel fuel lowers the amount of soot and other exhaust emissions, with the exception of HC [09]. Waste tire oil and diesel fuel blends, in their binary form can be utilized in CI engines without modification and reported that adding an alcohol to the waste tire oil-diesel blend enhanced performance and emission characteristics. The performance decreased marginally with increasing percentage of biodiesel blending with diesel, which infers that, the physical and chemical characteristics of the biodiesel is similar to diesel. NOx increase with lower CO, HC, and sulphar dioxide (SO_2) was reported as the blending percentage increased. NOx decreased with EGR [10]. In another comparative study of tested biodiesel blends, palm oil methyl ester demonstrated superior performance, combustion, and emission characteristics and can be utilized as a potential diesel substitute fuel without modifications in the transportation and agricultural sectors [11]. A study shows that rapeseed oil methyl ester blended with butanol as an alternative to diesel fuel can be used successfully to operate a CI engine with EGR without any modification to engine [12]. Some researcher using the simulation software for investigation of use of different fuel blends and result obtained showed that both ethanol and ether added to diesel fuel will lead to a decrease in engine BP with increase in BSFC while increasing BTE [13]. In another work, decrease in BP, higher BSFC, rise in NOx, lower CO and smoke emissions were reported by the CI engine run on biodiesel of flax, cotton seed, and palm oil. The use of EGR resulted in drop of NOx emissions and PP with higher CO emissions [14]. Sharanabasappa Saddu et.al., concluded that an used temple oil (UTO) cab be a potential raw material for the production of biodiesel called BTO and to evaluate its possibility for the substitute to petroleum fuel. The physical and chemical proportions were found well with the standard limits. The diesel engine could run satisfactorily on BTO blends with diesel fuel without any engine modifications. Hence it can be effectively used as alternate fuel for diesel engine as CO, HC, and NOx emissions were lower than diesel. [15].

1.2 Effect of IP, injection timing (IT) and combustion chamber (CC) on the performance of CI Engine

Experiments were performed on diesel engine run with biodiesel fuel derived from Pongamia oil to investigate the combustion, performance and emission characteristics. Hemispherical open type (HCC) and toroidal reentrant type combustion chamber (TRCC) and ITs were the variables. B20 exhibited comparable performance with TRCC because it promotes better mixing and combustion. A slightly delayed IT of 21 ^{o}bTDC showed enhanced performance, combustion, and emission characteristics [16]. In another study, retarding the IT from 23 ^{o}bTDC to 14 ^{o}bTDC showed increase in BTE and PP with lower NOx, HC, and CO. But this work reported higher smoke [17]. In a research work, the results showed increase in BSFC with decrease in BTE and reported that it is due to lower calorific value of biodiesel. Also it is reported that PP, heat release rate (HRR) and NOx increased but HC, CO and smoke lowered due to higher oxygen in biodiesel [18]. BTE of the ternary fuel blends is marginally lower than that of pure diesel. 27% BTE was reported with the ternary fuel blend B30 run engine at higher IP. The BSFC of ternary fuel blends is higher than that of neat diesel. As IP increased, a decrease in BSFC was observed for B30. With B20 blend fuel, the exhaust gas temperature (EGT) was lower and it decreased as IP increased. PP also decreased as IP increased. As compared to diesel, mahua biodiesel yielded higher PP [19]. The fuel IP is one of the important engine parameters that influences the diesel engine performance. The test performed on a four-stroke, single-cylinder, water-cooled diesel engine powered with

Jatropa curcas biodiesel at IP varying from 200 bar to 240 bar. In this test, B20 blend produced highest BTE, lowest EGT and BSFC as compared to all other biodiesel blends used in the study at IP of 220 bar. This work also demonstrated decrease in BTE, increase in BSFC and EGT as the percentage of biodiesel has increased [20]. Calophyluminophyllum biodiesel used to test the performance of CI engine at various IP. B20 biodiesel blend at 150 bar IP, resulted in the maximum BTE and minimal BSFC [21]. The performance and emissions of the diesel engines were assessed using algae biodiesel. The performance and emission characteristics at 220 bar IP are enhanced than at 200 bar IP due to reduced fuel droplet size and high-fine fuel spray. The engine's performance and emission parameters greatly improved at 30^0 bTDC [22]. In comparison study to the original IT 27 ºbTDC, the experimental work using Annona methyl ester blends at varied fuel IT revealed 13.5% reduced, 11.9% reduced BSFC and 6.4% greater BTE with higher NO at 33 ºbTDC [23].

1.3 Biodiesel fuelled CRDI Engine

The investigations were carried out to study the impact of IP and IT on the parameters of combustion and emissions of common-rail direct injection (CRDI) diesel engine run on waste cooking oil biodiesel-fueled. The biodiesel's fuel properties, such as its fatty acid makeup, were measured and contrasted with those of regular diesel fuel. Two injection pressures (80 and 160 MPa) and two IT from 25 to 0 after top dead centre (aTDC) were used in the engine testing, which were carried out under two distinct engine loads. The findings demonstrated that, the biodiesel's indicated specific fuel consumption (ISFC) in relation to the IT was higher than the diesel fuels. PP and HRR were slightly lower than regular diesel fuel. CO, HC and smoke emissions were reduced with biodiesel, especially fuel IP was high but with higher NOx [24]. An experimental study using diesel-tung oil-ethanol blended fuels with varying volume fraction ratios has been conducted to examine the performance, emissions, and combustion characteristics of CRDI engine. To test the engine, various injection strategies were used at different engine loads. The results of the experimental work showed that the blended fuels had a slightly shorter combustion duration (CD), a significantly longer ignition delay (ID), and greater PP and HRR as compared to diesel fuel. As tung oil and ethanol volume percentage grew, so did the BSFC and BTE. The blended fuel emitted more CO when the engine was running at low speeds, and more HC when tung oil and ethanol were added. The blends showed marginally increased NOx emissions at high engine loads but decreased NOx at low engine loads. At high engine loads, the amount of smoke released was significantly reduced. Ethanol additions generally had a greater impact on engine performance than tung oil [25]. This study examined the effects of altering the fuel blend ratio and fuel IP on CRDI engine performance run on blend of diesel and plastic oil. Diesel, plastic pyrolysis oil, and other fuel blends range in percentage from 5:95% to 15:85%, with different fuel IP of 400 bar, 500 bar, and 600 bar. Diesel engines might run on plastic oil mixtures without requiring any changes to the engine. The findings demonstrate that as fuel IP rises, BTE rises. For B15 fuel blend, the engine with the fuel IP of 600 bar provides superior BTE with lower emissions under full load conditions [26]. Experiments were conducted on CRDI system assisted CI engine to investigate its performance, exhaust emissions, and combustion parameters using diesel that contained 25% blended zizipus jujube methyl ester

(ZJME25). Moreover, ZJME25 aluminium oxide nanoparticles were added as an additive using an ultrasonicator and a mechanical homogenizer in mass fractions of 25 ppm (AONP 25) and 50 ppm (AONP 50). At all operational loads, a significant reduction in BSFC and exhaust emissions was observed for fuel mixed with aluminium oxide nanoparticles. The results also showed a significant improvement in HRR and BTE as a result of adding of aluminium oxide nanoparticles to the biodiesel–diesel blend [27]. The results of the investigation, which were based on a study of a four-stroke CRDI engine powered by waste plastic oil both with and without an EGR, showed that the engine could run well with a 30% waste plastic oil blend without the need for any modifications. Improvement in BTE by 2-3%, higher PP, HRR and NOx, rest of emission HC. CO and Smoke marginally increased for P30 blend. HRR, PP, and BTE decreased as a result of the thermal dilution and chemical effects of EGR introduction. Due to improper combustion, EGR complicates CO, HC, and soot emissions. With the 20% EGR, engine gave 36.3% reduction in NOx [28]. Another studies with blends SME:MO with diesel in CRDI engine was carried out. MO was blended due to its higher ignition and oxidative stability. The addition of MO:SME improved the BSFC of enriched biodiesels near to pure diesel due to decreased kinematic viscosity with increase calorific value (CV) but CO, HC and NOx emission increased. EGR limits the emission in CRDI engine [29]. Experimental study on single cylinder diesel engine with CRDI system was carried out with IT and IP. It was observed at certain load condition (80 & 100 % load) that BTE showed the increasing trend with increasing IT value up to 10^0 BTDC beyond it declined. HC emissions reduced with retarded IT while CO and smoke emissions increased drastically up to -10^0bTDC and decreased beyond the said IT. However NOx emissions increased with advanced IT. With increased IP, BTE increased up to 900 bar and beyond this pressure the BTE reduced. HC and CO emissions showed similar trends for both higher loads with reduced values at 900 bar. These emissions increased beyond 900 bar. NOx emissions increased with increased IP [30].

1.4 Hydrogen use in Diesel Engine

Experiments were done on a diesel engine with hydrogen in the dual fuel (DF) mode and hydrogen with DEE as ignition source. Hydrogen in both DF and with DEE operation showed an increase in BTE by about 22% and 35%, respectively compared to diesel. Significance reduction in NOx, CO, carbon dioxide (CO_2) and Smoke was reported [31]. The CFD analysis along with the experimental investigations carried out to compare the hydrogen–diesel DF combustion and emissions by induction and direct injection methods. The conclusion by researcher is that the hydrogen–diesel co-fueling will solve the drawback of lean operation of HC fuels such as diesel, which are hard to ignite and results in reduced BP by reducing misfires, improving emissions, performance and fuel economy [32]. Hydrogen-powered IC engines with near-zero emissions and higher BTE than diesel fuel are an attractive automotive solution that need to be developed [33]. Hydrogen mixed with air was induced from an intake port and diesel oil was injected into the cylinder in a four-stroke single cylinder diesel engine. The ratio of the hydrogen was changed from 0 to 80 %. When hydrogen is mixed with inlet air, smoke enormously decreased, other emissions of HC, CO and CO_2 decreased with increase in the ratio of the hydrogen. BTE was slightly lower than that in ordinary diesel combustion. In particular, both smoke and NOx are almost zero while HC are almost the same when the IT of diesel oil is extremely advanced about 40 or 50 degrees before TDC. Very low CO_2 and relatively low HC are achieved when hydrogen fuel is added to the air from an intake port. In DF combustion with hydrogen, the maximum value and the gradient of the HRR are smaller in general than those in ordinary diesel combustion [34]. In another study researcher added hydrogen to intake air of diesel truck having four cylinder engine during running test to investigate the effect of hydrogen addition on the engine's fuel consumption and exhaust gas composition. The observed effects of hydrogen addition in JE05 actual driving mode and constant speed driving modes were similar and corresponded to the previous studies conducted using an engine dynamometer. The benefits included a reduction in diesel consumption and a reduction in CO_2, CO, and smoke emissions but NOx emission increased [35]. Experimental studies were performed successfully on a four stroke, single cylinder CI engine DF mode with load range (0-14 kg.). The impact of hydrogen addition on performance and emission of biogas-diesel DF engine were analysed, which reveal hydrogen-biogas-diesel was an optimum blend, It was clearly indicate that enriching and blending hydrogen with biogas in DF engine has a significant role in improving the performance and reducing the emissions of CI engines, thus proving as a sustainable solution for the future [36]. Now-a-days, hydrogen gas is continuously proving its potency as a sustainable and clean energy carrier in current fossil fuel deploying stage with higher specific energy and zero polluting energy source [37]. The use of up to 20% of hydrogen as a replacement fuel to diesel oil has provided safe operation and did not require modifications of the engine original settings. The application of hydrogen as fuel reduced CO_2 emissions by up to 12%. This indicates the employment of hydrogen as a useful strategy to reduce the global warming impacts of engine exhaust gas. That will depend on the hydrogen source and the amount of upstream CO_2 associated with hydrogen production [38]. In experimental investigations on a hydrogen – diesel DF engine at different compression ratios and studied the effect of air intake temperature on NO_x, They observed that BTE increased with increased percentage of hydrogen. They reported sharp increase in NO_X when temperature is increased from 65–85 ^{0}C [39]. Researcher conducted experiments on a single cylinder four stroke diesel engines coupled to an electric generator with hydrogen enrichment and using EGR technique. They observed that use of hydrogen in DF mode with EGR (25 percent) resulted in reduced smoke level, particulate and NO_x emissions [40]. Hydrogen cannot be used as a sole fuel in a CI engine, since the compression temperatures is not enough to initiate the combustion due to its higher self-ignition temperatures [41].

Gap identified in the literature:

Gaps in the operation of CI, CRDI, and DF engines: the following gaps are observed through literature review for further investigations.

1. Conventional fuel injection systems with a limited IP of up to 300 bar are used in the majority of biodiesel-fueled engine research, resulting in poor BTE and increased emissions. These disadvantages can be effectively minimized through the use of various injection techniques.
2. Numerous researchers have studied fuel injection at high pressure using a CRDI arrangement and an electronic control unit (ECU) for a four-stroke, single-cylinder diesel engine that runs on diesel fuel. There are not many reports on the usage of biodiesel in these configurations.
3. Very less literature is available on biodiesel with hydrogen combination in DF CRDI engine.

Conclusions

Thorough literature review was conducted to report the performance of diesel engines fueled with various fuel combinations in CI, CRDI, and DF modes. From this current review work, following critical conclusions can be drawn:

1. The stability, fuel flexibility and higher BTE of CI engines make them popular in applications like, Agriculture, power generation and automotive Industries.
2. To meet the stricter emission standards and get better performance, they needed to significantly change their design standards. However, further research is needed to fully understand the causes of these engines excessive emissions before appropriate modifications
3. In comparison with the neat diesel mode of engine operation, use of biodiesel in conventional CI engines causes decreased engine performance, lower or greater emissions of HC, CO, Smoke, and NOx, as well as higher ID, CD, and HRR.
4. Engine performance is significantly impacted by CC shape, IT advancement or retardation and IP.
5. When compared to CI mode of operation, biodiesel-operated CRDI engines exhibit improved engine performance, lower emissions of HC, CO, and smoke.
6. DF technique reduces emissions of engine with enhanced fuel economy.

References

1. Kuntang Winangun, Atok Setiyawan, Bambang Sudarmanta, Indah Puspitasari, Eniya Listiani Dewi, Investigation on the properties of a biodiesel-hydrogen mixture on the combustion characteristics of a diesel engine, Case Studies in Chemical and Environmental Engineering 8 (2023). 100445 doi.org/10.1016/j.cscee.2023.100445
2. C. N. Pratheeba and Preeti Aghalayam, Effect of Exhaust Gas Recirculation in NOx Control for Compression Ignition and Homogeneous Charge Compression Ignition Engines- The 12th International Conference on Combustion & Energy Utilisation– 12ICCEU
3. H. E. Saleh, Effect of exhaust gas recirculation on diesel engine nitrogen oxide reduction operating with jojoba methyl ester, Renewable Energy 34 (2009) 2178–2186, doi:10.1016/j.renene.2009.03.024
4. Mustafa Karagöz, Investigation of performance and emission characteristics of an CI engine fuelled with diesel – waste tire oil – n butanol blends, Fuel 282 (2020) 118872, doi.org/10.1016/j.fuel.2020.118872
5. Shehata M.S. Emissions, performance and cylinder pressure of diesel engine fuelled by biodiesel fuel, ***Fuel,*** 112: 513-522, 2013, doi:10.1016/j.fuel.2013.02.056.
6. Nagata Koji. State-of-art technologies for diesel common rail system. SAE 2004-28-00:68, 442–474.
7. Zbigniew Stepien, A Comprehensive Overview of Hydrogen-Fueled Internal Combustion Engines: Achievements and Future Challenges, Achievements and Future Challenges. Energies 2021, 14, 6504, https://doi.org/10.3390/en14206504
8. Syed Ameer Basha, K. Raja Gopal, S. Jebaraj, A review on biodiesel production, combustion, emissions and performance, Renewable and Sustainable Energy Reviews 13 (2009) 1628–1634, doi:10.1016/j.rser.2008.09.031
9. ZehraSahin, Orhan N. Aksu,-Experimental investigation of the effects of using low ratio n-butanol / diesel fuel blends on engine performance and exhaust emissions in a turbocharged DI diesel engine ,Renewable Energy 77 (2015) 279-290, doi.org/10.1016/j.renene.2014.11.093
10. Mustafa Karagöz, Investigation of performance and emission characteristics of an CI engine fuelled with diesel – waste tire oil – butanol blends, Fuel 282 (2020) 118872, https://doi.org/10.1016/j.fuel.2020.118872
11. K. M. Akkoli, P. B. Gangavati, N. R. Banapurmath and V. S. Yaliwal, Comparative study of various biofuel combinations derived from agricultural residues on the performance and emissions of CI engine, International Journal of Sustainable Engineering, 2020, Vol. 13, No. 2, 140–150, doi.org/10.1080/19397038.2019.1634774
12. Pratik swami Et.al ,Effect of Rapeseed Oil Methyl Ester-Butanol Blend at Various EGR and VCR on Emission Characteristics of Diesel, International Journal for Innovative Research In Science and Technology.2017,Vol.04,Issue 03,93-98 pp

13. M.A. Hamdan, Runa Haj Khalil, Simulation of compression engine powered by Biofuels, Energy Conversion and Management 51 (2010) 1714–1718, doi:10.1016/j.enconman. 2009.10.037
14. Shehata M.S. Emissions, performance and cylinder pressure of diesel engine fuelled by biodiesel fuel, ***Fuel,*** 112: 513-522, 2013, doi:10.1016/j.fuel.2013.02.056.
15. Sharanabasappa Saddu, Performance and Emission Parameters of Compression-Ignition (CI) Engine Fuelled with Waste or used Temple Oil Biodiesel at Blends, International Journal for Applied Science – Research & Review. Vol.5 No.4:18.,DOI: 10.21767/2394-9988.100083
16. S. Jaichandar , P. Senthil Kumar , K. Annamalai, Combined effect of injection timing and combustion chamber geometry on the performance of a biodiesel fueled diesel engine, Energy 47 (2012) 388-394, doi.org/10.1016/j.energy.2012.09.059
17. M. Mani, G. Nagarajan, Influence of injection timing on performance, emission and combustion characteristics of a DI diesel engine running on waste plastic oil, Energy 34 (2009) 1617–1623, doi:10.1016/j.energy.2009.07.010
18. D.H. Qi, H. Chen, L.M. Geng, Y. ZH. Bian, Experimental studies on the combustion characteristics and performance of a direct injection engine fueled with biodiesel/diesel blends, Energy Conversion and Management 51 (2010) 2985–2992, doi:10.1016/j.enconman.2010.06.042
19. Pani Sharanappa, Mallinath C. Navindagi. Investigation of performance and Combustion Characteristics of DI Diesel Engine Fuelled with Ternary Fuel Blend at Different Injection Pressure. World Journal of engineering and Technology.2017; 5: 125-138
20. Sirivella Vijaya Bhaskar, G. Satishbabu. Effect of Injection Pressure on Performance of CIDI Engine Fuelled with Jatropha Curcas Biodiesel. American Int Journal of research in Science, Technology, engineering and Mathematics. 2016; 16-206: 14-18
21. Suchith Kumar M T, dhananjaya D A. Study on Effect of Injection Pressure on Performance Characteristics of Diesel Engine Using Different Blends of Biodiesel, Int Journal of Emerging Technologies in Computational and Applied Sciences 2014; 14-160: 441-444
22. S. Mahalingam, B.R. Ramesh Babu and B. Balaji. Emission analysis of DI-Diesel engine at different injection Pressures using Jatropha and Rubber seed oil blended with diesel. IOSr journal of Mechanical and Civil Engineering 2014; 78-80
23. K. M. Mriyunjaya Swamy, D. K. Ramesha. The Effect of Injection Pressure and Injection Timing on Performance and Emission Parameters with Algae Oil Methyl Ester Blend as a Fuel for CI engine, Int Journal of Scientific and Research publications, 2015; 5(11): 210-215
24. Hwang Joonsik, Qi Donghui, Jung Yongjin. Choongsik Bae. Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel. Renew Energy 2014; 63: 9–17.

25. D.H. Qi, K. Yang, D. Zhang, B. Chen, Combustion and emission characteristics of diesel-tung oil-ethanol blended fuels used in a CRDI diesel engine with different injection strategies, Applied Thermal Engineering 2017, 111, 927–935.
26. G. Balaji, M. Karthik, G. Dinagaran, P. Vasanth Kumar. Experimental Investigation of Plastic Oil Blends on CRDi Engine for Various Fuel Injection Pressures, IOP Conf. Series: Materials Science and Engineering 2021, 1130, 012075
27. C. Syed Aamal, C.G. Sarvanan, Effect of nano metal oxide blended biodiesel on CRDI diesel engine, Ain Shams Engineering Journal 2015, Fuel 90, 854 -874.
28. Ayodhya AS, Lamani VT, Bedar P, Kumar GN. Effect of exhaust gas recirculation on a CRDI engine fueled with waste plastic oil blend. Fuel. 2018; 227:394-400.
29. H.S. Homan, P.C.T. deBoer and W. J McLean. The effect of fuel injection on NO_x emission and undesirable combustion for hydrogen fueled piston engines. SAE 780945.
30. Basavarajappa D. N, Banapurmath N. R, Khandal S. V, Manavendra G. Performance evaluation of common rail direct injection (CRDI) engine fuelled with uppage oil methyl ester (UOME). Int J Renew Energy Dev 2015. doi.org/10.14710/
31. Masood M, Mehdi S. N and Reddy P. R. Experimental investigations on hydrogen – diesel dual fuel engine at different compression ratios. ASME Journal of Engineering. Gas turbines power, 129, 2007, 572- 578.
32. R. Senthil, R. Silambarasan, G. Pranesh. The influence of injection timing on the performance and emission characteristics of an Annona methyl ester operated diesel engine. 2016. DOI: 10.1080/17597269.2016.1149768.
33. Shehata M.S. Emissions, performance and cylinder pressure of diesel engine fuelled by biodiesel fuel, ***Fuel,*** 112: 513-522, 2013, doi:10.1016/j.fuel.2013.02.056.
34. J.A. Schouten, J.P.J Michels, R. Jansssen- Van Rosmalen, Effect of H_2 –Injection on the thermodynamic and transportation properties of natural gas. International Journal of Hydrogen Energy 29, 2004, 1173-1180.
35. Toshiaki Kitagawa, Hiroyuki Kido, Nozomu, Nakamura, Masaya Aishima. Flame inertia in to lean region in stratified hydrogen mixture. International Journal of Hydrogen Energy 29, 2004, 1173-1180
36. Mahesh M.K., Neelu, Prakash C and Viswanathan. Review of fuel induction technologies for automotive hydrogen propulsion. International Mobility Engineering Congress and Exposition 2005, 317- 324
37. Furuhama S., Yamane K., Yamaguchi I. Combustion improvement in hydrogen fuelled engine. International Journal of Hydrogen Energy 2, 1977, 329-340.
38. Andre´ Marcelino de Morais, Hydrogen impacts on performance and CO2 emissions from a diesel power generator, I n t e r n a t i o n a l journal of hydrogen energy 38 (2013) 6857-6864, doi.org/10.1016/j.ijhydene.2013.03.119
39. Masood M, Mehdi S. N and Reddy P. R. Experimental investigations on hydrogen diesel dual fuel engine at different compression ratios. ASME Journal of Engineering. Gas turbines power, 129, 2007, 572- 578.

40. Saravanan N., Nagarajan G., Sanjay G., Dhansekaran C and Kalaiselvan K. M. Combustion analysis on a DI diesel engine with hydrogen in dual fuel mode. 2006, Fuel-92-258-264
41. Das L.M. Near term introduction of hydrogen engines for automotive and agricultural applications. International Journal of Hydrogen Energy, 27, 2002, 479- 487