Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 10, Issue 1; January-March, 2023, pp. 11-16

http://www.krishisanskriti.org/Publication.html

Experimental investigation on Common rail direct injection (CRDI) facilitated homogenous charge compression ignition (HCCI) engine powered by diesel and CGTSCPO

T. Sreenivasa Murthy[1], B. Jayachandraiah[2,] and B. Durga Prasad[3]

[1,2] Department of Mechanical Engineering, Jawaharlal Nehru Technological university, Anantapur -515002, Andhra Pradesh, India
[3] Department of Mechanical Engineering, Srikalahasteeswara Institute of Technology, Srikalahasti-517640, Andhra Pradesh, India.

Abstract—*Experimental tests were performed on direct injection (DI) homogeneous charge compression ignition (HCCI) for diesel, CGTSCPO20 and CGTSCPO10. Experiments were performed at different fuel injection timings (IT) to differentiate between HCCI operation and common rail direct injection (CRDI) operation. Pilot tests with a 60% load were conducted for this purpose, and a heat release rate (HRR) investigation was carried out. For HCCI operation, cool flames were seen 20º before the top dead center (bTDC), 55º bTDC for fuel IT advancements, etc. HCCI engines with firm fuel blends demonstrated decreased peak HRR. Due to decreased HRR, higher injection pressure (IP) lowers nitrogen oxides (NOx). Diesel, CGTSCPO10, and CGTSCPO20 achieved 40 ppm, 34 ppm, and 32 ppm NOx, respectively, in HCCI mode at IP 1000 bar and IT at 80º bTDC. Diesel, CGTSCPO10, and CGTSCPO20 had smoke opacities of 10 HSU, 17 HSU, and 20 HSU, respectively, under identical operating circumstances. The study's findings suggest that IP at 1000 bar and IT at 80º bTDC are the ideal operating parameters for reducing NOx and smoke while maintaining an acceptable level of HCCI engine brake thermal efficiency (BTE).*

Keywords: Homogeneous charge compression ignition (HCCI); CGTSCPO; NOx emission; Smoke emission.

1. INTRODUCTION

While diesel engines are quite effective at conserving fuel, they also produce exhaust and dangerous nitrogen oxides (NOx). Compression ignition (CI) systems work well and can use biodiesel. Innovative approaches must be employed to meet regulatory emissions standards. Homogeneous charge compression ignition (HCCI) was one of these concepts in late 1970. An HCCI engine's generated charge ignites immediately when it exceeds the chemical reaction's energy threshold. With an HCCI engine with an intake air temperature of 200°C and a low CR (less than 8), protracted combustion may be avoided with the exception of very low NOx and smoke; nevertheless, a configuration with high hydrocarbon (HC) smoke leads to poor combustion. As compared to conventional CI systems, brake thermal efficiency (BTE) has been shown to be 28% lower [1, 2]. Very early combustion phasing was seen with intake manifold injection at greater CR and load, along with higher HC, negative BTE, and more knock. HCCI tests using MTBE and diesel (50:50) indicated combustion phasing close to TDC because to auto-ignition delay [3]. HCCI engines produce much less NOx and pollutants when there is more HC and CO present. BTE and the use of alternative fuels (SFC) both saw a little reduction [4]. HCCI engines with fuel injection time (IT) that is 120° before top dead centre (bTDC) are characterised by small diameter multi-hole injectors, 8000 ppm HC output, and very early combustion phasing [5, 6]. Divided injection Early ignition, very high CO and HC levels, and low NOx are characteristics of HCCI engines [7,8]. A spray angle of 80 degrees and a bTDC of 40 to 60 degrees exhibited more smoke than in diesel mode, with 1000 to 2500 ppm HC but higher SFC [9]. The amount of smoke produced remained constant even though the annular combustor (TCC) produced less NOx and HC [10, 11]. Many fuel injections resulted in an increase in NOx, despite a reduction in HC and CO levels [12, 13]. For HCCI engines, thin spray cone injectors displayed increased CI mode BTE [14]. High negative valve overlap yields reduced NOx and smoke with great combustion stability at low loads (NVO). Larger loads have been shown to create greater NOx because to knocking combustion and quicker pressure rise rates [15]. The multi-injection mechanism of the HCCI engine reduces NOx and emissions. Proper blending of improved CC designs has been identified as a problem [16]. HCCI engines may run at a lower BMEP (2.1 bar to 4.3 bar) and yet produce less NOx and have a negative BTE [17] during the early phases of cylinder injection. An effective method to reduce NOx may be variable valve timing (VVT) with high-pressure circuit exhaust gas recirculation (EGR) without cooler [18]. Fuel IT has to be optimised in order to stop a deflagration [19–21]. High outside EGR reduces concussion danger whereas speed, load, and interior EGR increase risk [22]. Comparable efficiency to CI conditions may be attained with less gaseous emissions by many injections into the cylinder with the last injection being close to the cool flame. In comparison to conventional diesel engines, HCCI engines with manifold and in-cylinder injection release less NOx and exhaust [3, 8]. The most stable combustion is shown by charge stratification in HCCI engines. When high HRR is seen, low HRR is reported [23, 24]. The HCCI engine manufacturing method may be a practical technical solution to increase fuel efficiency while lowering emissions [25]. The following is a critical analysis of the little amount of material on the use of biofuels in HCCI engines.

Compression ignition (CI) engines running on UME (upgraded methyl ester) and CNG were investigated for DF and HCCI operation. While the DF process performs worse than conventional mono-fuel production, it emits less gases, including nitrogen oxides, hydrocarbons, and carbon monoxide. In terms of breakdown thermal efficiency (BTE), the HCCI engine performed better than the DF operating mode but less well than the traditional CI mode. Although HC emissions are high, other pollutants including CO, NOx, and soot are minimal. Emissions of greenhouse gases and nitrogen oxides decreased by almost 98% and 94%, respectively [26].

According to published research, a novel operating concept for homogeneous charge compression ignition (HCCI) employing CRDI further decreases particulate matter (PM) and NOx emissions to almost zero levels with a somewhat reduced BTE. The operation, emissions, and combustion performance of the alternative fuel injection-equipped CI, CRDI, and HCCI engine systems were thoroughly examined [27].

Compressed natural gas (CNG), air, and diesel/fuel methyl ester (HOME) were added in another study on HCCI engines to manage the start of combustion in a modified HCCI engine. According to reports, the engine cannot be run in HCCI mode with a BMEP of less than 2.5 bar because system restrictions prevent the intake air temperature from rising beyond 145oC, and at a BMEP of 4 bar the combustion rate increases significantly. Nitrogen oxides (NOx) and emissions were greatly decreased in the HCCI engine's operating mode, while carbon monoxide (CO) and hydrocarbons (HC) emissions were found to be greater. The brake thermal efficiency was shown to be greater for HCCI engine running than for dual fuel when driven with certain fuel mixes [28].

Diesel and biodiesel were pumped into the intake manifold during the engine test, which was conducted in HCCI (homogeneous charge compression ignition) mode. The intake air temperature with an air preheater ranges from 50 to 80°C for diesel and 55 to 85°C for biodiesel. The cooling water temperature for diesel and biodiesel operation ranges from 40 to 60 °C. The HCCI technique for creating diesel and biodiesel engines results in a large 98% decrease in nitrogen oxide (NOx) emissions, a 65-75% reduction in exhaust emissions, and a reduction of 35-45% in brake thermal efficiency (BTE). On the other hand, HCCI engine systems employing diesel and biodiesel have 30–40% greater carbon monoxide (CO) emissions and hydrocarbon (HC) emissions that are 20–25 times higher. Nevertheless, compared to the CI engine design, the peak pressure (PP) and heat release rate (HRR) are decreased by 20–25% [29].

Using diesel, CGTSCPO20, and CGTSCPO10 test fuels, this work's objective was to assess the performance of an in-cylinder-injected HCCI engine in order to identify the ideal operating parameters for reducing soot and NOx emissions while the engine is running at a respectable BTE.

2. MATERIALS AND METHODS.

Table 1 summarises the characteristics of Diesel, CGTSCPO20, and CGTSCPO10 as determined by the Bengaluru test house in Bangalore.

Table 1. Physiochemical properties of CGTSCPO10 and CGTSCPO20

Property	BLENDED CGTSCPO10	BLENDED CGTSCPO20
Kinematic Viscosity (Cst)	3.95	4.1
Calorific value (MJ/kg)	44.45	44.3
Cetane number	51	48
Density at 30 ºC (g/cc)	0.8	0.84
Flash point (ºC)	76	74
Fire point (ºC)	85	87
pH	5.2	5.3

Diesel, CGTSCPO20, and CGTSCPO10 are operating in HCCI mode on a single-cylinder, DI hydraulic CI engine. With the proper modifications, the CI engine was run in HCCI mode using the fuel configuration indicated in Figure 1. Table 2 provides the engine specs that were used. Several emissions are measured using exhaust gas analyzers and Hartridge smoke metres, and a TRCC (Toroidal re-entrant combustion chamber) was employed in this investigation.

Figure 1. Experimental setup

Table 2 . Engine Specifications

Parameter	Specification
Engine type	Kirloskar makes single-cylinder four-stroke direct-injection diesel engine
Nozzle opening pressure	205 bar
Rated power	5.2kW@1500rpm
Cylinder diameter	87.5
Stroke length	110
Compression ratio	17.5:1
Injection timing	23^o TDC
Type of cooling	Water

3. THE RESULTS AND DISCUSSION

The test findings for injected diesel, CGTSCPO20, and CGTSCPO10 acquired using a modified CI engine running under HCCI conditions are covered in this section. Using CRDI injectors with multi-hole and single-hole injectors, pilot oil is injected into the cylinders using the in-house developed CRDI system, which can inject oil at any crank angle (CA) and duration with the help of the ECU at the desired injection pressure (IP) ranging from 600 to 1200 bar HCCI stage.

The fuel mixture detailed in this section, together with the 7-hole injectors, powers HCCI engines. Optimal operating settings, such as the following, were maintained: CR: 17.5; speed: 1500 rpm; IP: 1000 bar; CC: TRCC; nozzle: 7 holes, 0.18 mm in diameter, 60% load. All injection oils have different injection times. A fuel adjustment is made to keep the engine running at a constant 1500 rpm. Injection Timings for selected oils include 0°, 15°, 35°, 55°, and 80°. Whereas advanced extended injection timing of 35^o, 55^o, and 80^o relates to HCCI mode of engine operation, fuel IT of 0^o, 15^o bTDC corresponds to BTE mode chosen in CRDI mode.

3.1 Impact of IT on BTE

Fig. 2 depicts the impact of IT on BTE at 60% load for CRDI and HCCI engine operating modes. When fuel IT advances, BTE reduces, as can be observed in Figure 3. In CRDI mode on a diesel powered engine, a mixture of CGTSCPO20 and CGTSCPO10 demonstrated an increase in BTE levels up to 15^o bTDC. Modern IT did, however, detect much lower BTE levels in IT at 80^o bTDC compared to CRDI mode in the HCCI mode of operation.

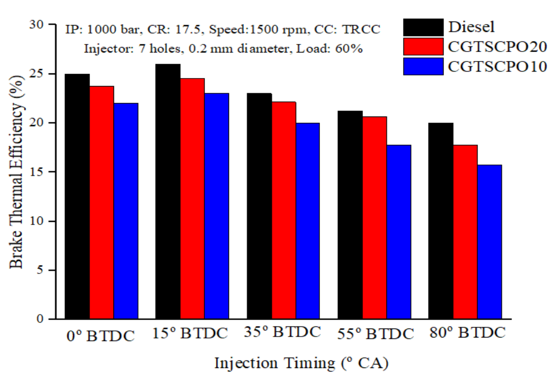

Figure 2. IT Effect on BTE

Hence, a lower BTE was found with fuel IT of 80^o bTDC. Increased wall wetness, which in turn causes an increase in HC emissions, is the cause of the trend that has been observed. Carbon deposits are created as a result of the increased spray coming into direct contact with the CC wall as the piston advances away from TDC. Because of their increased calorific value and weight and reduced volatility, CGTSCPO20 and CGTSCPO10 perform better than diesel fuels.

Diesel, CGTSCPO20, and CGTSCPO10 produced 20%, 17.75%, and 15.75% BTE at 80^o bTDC in HCCI mode, compared to 26%, 24.55%, and 23% BTE in CRDI mode for diesel and biodiesel, respectively.

3.2 Impact of IT on Smoke opacity

Figure 3 depicts the fuel IT performance for CRDI and HCCI engine running modes at 60% load for smoke opacity.

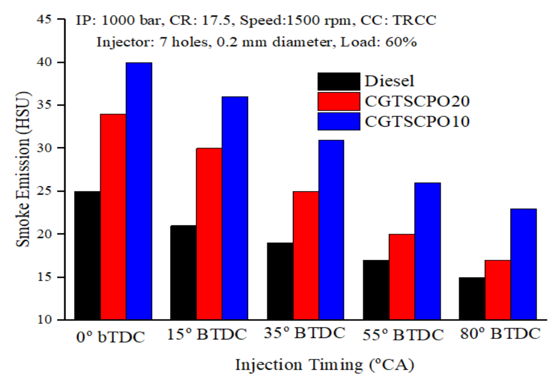

Figure 3. IT effect on Smoke

A mixture of CGTSCPO20 and CGTSCPO10 demonstrated a decrease in smoke emission levels down to 15^o bTDC when used in CRDI mode on a diesel engine. Modern ITs, on the other hand, were found to have lower levels of smog emissions during HCCI operation, with ITs at 80^o bTDC having much fewer emissions than CRDI models.

Innovative fuel technology lowers engine gas emissions. Improved combustion parameters of the injected fuel combination are somehow ensured by the creation of the air-fuel mixture. As compared to the diffusion phase in the combustion chamber without fuel-containing sections, premixed combustion results in higher fuel combustion levels.

Because of their significantly greater molecular structure and viscosity compared to diesel, CGTSCPO20 and CGTSCPO10 have higher emissions, which leads to lower combustion temperatures in the cylinder. In the HCCI instance, diesel, CGTSCPO20, and CGTSCPO10 were used to produce HSU 15, HSU 17, and HSU 23 vapours at IT of 80^o bTDC. In the CRDI case, diesel and biodiesel were used to produce HSU 21, HSU 30, and HSU 36 vapours at IT of 80^o bTDC.

3.3 Impact of IT on HC and CO

Figures 4 and 5 demonstrate, respectively, how IT affects the HC and CO pollution of CRDI and HCCI engines operating at 60% load.

In CRDI mode on diesel-powered engines, CGTSCPO20 and CGTSCPO10 blends exhibit the lowest HC and CO emission concentrations up to 15º bTDC. However, in the HCCI system, advanced IT had substantially greater levels of HC and CO contamination, and at 80º bTDC, IT had much higher amounts of HC and CO vapours than under CRDI settings.

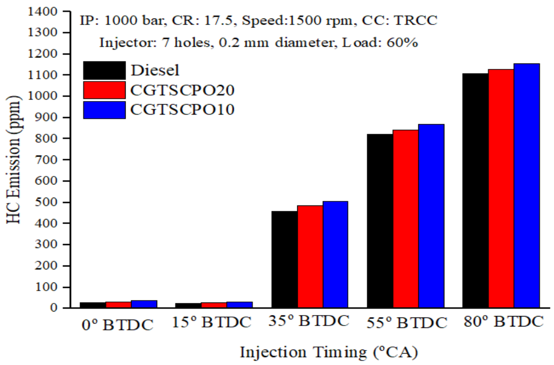

Figure 4. IT effect on HC

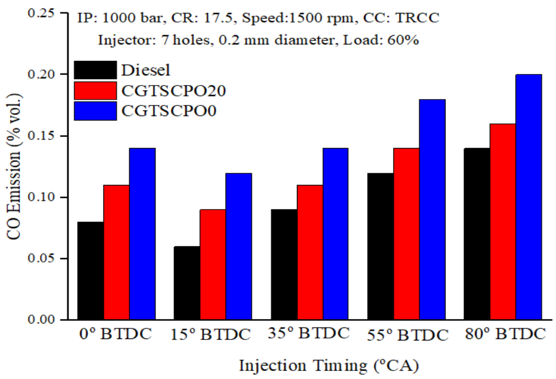

Figure 5. IT effect on CO

The findings show that HC and CO levels rise with the number of injections. Around 80º bTDC, a high HC release was seen. This may be because using a 7-hole needle while the piston is far from TDC causes wall wetness. In contemporary IT, crankcase dilution is also seen. When compared to diesel, CGTSCPO20 and CGTSCPO10 had greater HC and CO emissions. When these alternative fuels are used, the brakes lower engine temperatures, which is linked to a decrease in the premixed combustion phase, which is the cause of these problems. The lower power and larger mass of the engine operating on the mixture of CGTSCPO20 and CGTSCPO10 may further contribute to further incomplete combustion, which would then result in increased UBHC emissions. Due to its higher oxidation rate, CGTSCPO20 performed better than CGTSCPO10.

While utilising diesel, CGTSCPO20, and CGTSCPO10 blends, HC emissions were measured at 1108 ppm, 1128 ppm, and 1156 ppm. When using diesel, CGTSCPO20, and CGTSCPO10 in accordance with CRDI requirements, HC emissions were measured at 24 ppm, 28 ppm, and 32 ppm.

Diesel, CGTSCPO20, and CGTSCPO10 blends predict CO emissions of 0.14% vol, 0.16% vol, and 0.22% vol, respectively, at IT at 80º bTDC in HCCI mode, and% vol for diesel, CGTSCPO20 and CGTSCPO10 in CRDI mode volume.

3.4 IT effect on NOx

Figure 6 illustrates how IT affects NOx emissions for CRDI and HCCI engine operating modes at 60% load. Using a mixture of CGTSCPO20 and CGTSCPO10 in CRDI mode on a diesel engine resulted in a rise in NOx levels of up to 15º bTDC. In contrast to the CRDI model, where a considerable decrease in NOx emission was seen for IT at 80º bTDC, contemporary IT found lower NOx emission levels in the HCCI system. The HRR may be decreasing with the gas temperature in the combustion chamber, which might be the cause of the observed trend. Moreover, as shown in Figure 7, the burn phase of sophisticated IT lags behind owing to the rise in ID.

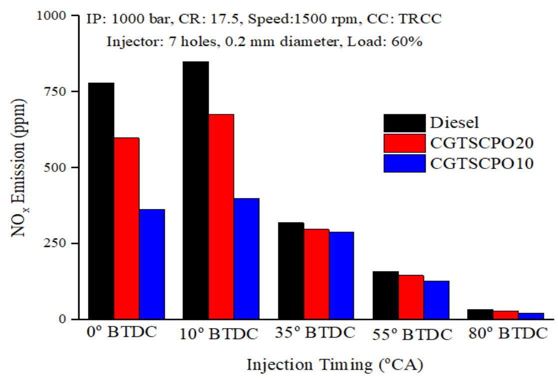

Figure 6 IT Effect on NOx

For diesel, CGTSCPO20 and CGTSCPO10 blends, and 850 ppm, 675 ppm, and 400 ppm CRDI status, respectively, NOx emissions are estimated to be 30 ppm, 30 ppm, and 22 ppm.

3.5 Effect of IT on HRR

The HRR fluctuation of the CI engine in CRDI and HCCI modes at 60% load is shown in Fig. 7. With CRDI and fuel IT less than 35º bTDC, the engine operates similarly to normal CI engines. Minimal corrosion was seen during HCCI mode engine running with fuel IT of 35°, 55°, and 80° bTDC, suggesting a gentle flame pattern in the premixed charge as a result of low temperature combustion (LTC). Upgrades to HCCI are only feasible when Technology develops further. For the ITs at 55º bTDC and 80º bTDC, the cold flame always begins at 340º CA, which is 20o bTDC; however, no cool flame is seen for the other ITs selected to perform the CRDI test. In order to better comprehend the fundamentals of HCCI operations, several ITs were chosen.

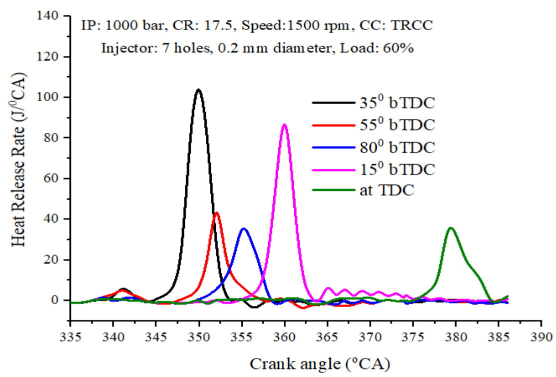

Figure 7 IT Effect on HRR

At 60% load in the aforementioned test, very high HC and CO and low BTE were discovered. The apparent contraction of the crankcase was another problem found during the examination. Every oil that was tested showed crankcase dilution. The aforementioned issues are the result of severely wetted walls brought on by extremely early oil injection.

4. CONCLUSION

The following findings about in-cylinder direct injection HCCI engines are made based on the study:

Both CGTSCPO10 and CGTSCPO20 biodiesel work well in HCCI engines, and HRR analysis at 60% load clearly demonstrates a soft flame at 20° bTDC.

- The creation of 55° bTDC Fuel IT etc. marked the beginning of the HCCI process.
- Lower peak HRR for HCCI engines, followed by a decline.
- At IP 1000 bar and IT 80° bTDC, reported values for Diesel, CGTSCPO20, and CGTSCPO10 HCCI were 42 ppm, 36 ppm, and 34 ppm, respectively. Higher IP reduced NOx as a result of lower HRR.
- Diesel, CGTSCPO20, and CGTSCPO10 can all produce low emissions for 9 HSU, 15 HSU, and 17 HSU under the same operating circumstances.
- The levels of HC and CO are high here.

Generally, it can be said that the best setting for NOx and smoke reduction in HCCI mode with a little lower brake temperature is IT with IP 1000 bar and 80° bTDC (BTE).

1. Christensen M, Hultqvist A, Johansson B. Demonstrates the multi-fuel capability of a homogeneous charge compression ignition engine with variable compression ratio. SAE Paper 1999-01-3679; 1999.
2. Yao Mingfa, Zheng Zhaolei, Liu Haifeng. Progress and recent trends in homogeneous charge compression ignition (HCCI) engines. Advances in Energy and Combustion Science 35 (2009) 398–437.
3. Suzuki H, Koike N, Odaka M. Combustion control methods for homogeneous charge diesel engines. SAE Paper 980509; 1998.
4. Avinash Kumar Agarwal, Akhilendra Pratap Singh, Jithin Lukose, Tarun Gupta. Characterization of Exhaust Particulates from a Homogeneous Charge Compression Ignition Internal Combustion Engine with Diesel Fuel. Journal of Aerosol Science 2013, 58. 71.
5. Takeday y, Keiichi N. Emissions characteristics of premixed lean diesel combustion with very early stage fuel injection. SAE Paper 961163; 1996.
6. Nakagome K, Shimazaki N, Miimura K, Kobayashi S. Combustion and emissions characteristics of a premixed lean diesel internal combustion engine. SAE Paper 970898; 1997.
7. Yokota H, Kudo Y, Nakajima H, Kakegawa T, Suzuki T. Low concept for low emission diesel combustion. SAE Paper 970891; 1997.
8. Suzuki T, Kakegawa T, Hikino K, Obata A. Developments in diesel combustion for commercial vehicles. SAE Paper 972685; 1997
9. Iwabuchi Y, Kawai K, Takeshi S, Takeda Y. New Concept Diesel Engine Combustion System Test - Premixed Compression Ignition Combustion, SAE Paper 1999. 1999-02-0185.
10. Kimura S, Aoki O, Ogawa H, Muranaka S, Enomoto Y. A new combustion concept for ultra-clean and efficient small direct-injection diesel engines. SAE Paper 1999-01-3681; 1999.
11. Kimura S, Aoki O, Kitahara Y, Aiyoshizawa E. Ultra-clean combustion technology combining low temperature and premixed combustion concepts to meet future emission standards. SAE Paper 2000-01-0200; 2000.
12. Morita A, Iwashiro Y, Aoyagi Y, Hashizume T. Observe the diesel combustion process in multi-stage injection. In: Proceedings of Thiesel 2000 Thermohydrodynamic Processes in Diesel Engines. p. 447-52.
13. Nishijima Y, Asaumi Y, Aoyagi Y. Direct water injection impingement spray system for premixed lean diesel combustion control. SAE Paper 2002-01-0109; 2002.
14. Walter and Gatellier Near-zero NOx emissions and high fuel efficiency diesel engine: NADITM concept using dual-mode combustion. In Oil and Gas Science and Technology, Volume 58, Pages 101–114, 2003.
15. Shi L, Deng K, Cui Y. In-cylinder advance fuel injection and negative valve overlap on homogeneous charge compression ignition combustion of diesel fuel. P I Mech Eng D-J Aut 2005;219:1193-201.
16. Su WH, Zhang XY, Lin TJ. Pulse spray, heat release, emissions and efficiency study of a compound diesel HCCI internal combustion engine. In: ASME-ICE ASME Internal Combustion Engines Section Proceedings. Fall Technical Conference, ICEF2004–927; 2004.
17. Nathan Swami S, Mallikarjuna JM, Ramesh A. Effect of mixture preparation in a diesel HCCI engine using early in-cylinder injection during the intake stroke. International Journal of Automotive Technology 2007;8:543-53.
18. Bression G, Soleri D, Savy S, DCGTSCPO20ux S, Azoulay D, Hamouda HB. Study on methods to reduce HC and CO emissions from diesel HCCI. SAE Paper 2008-01-0034; 2008.
19. Harada A, Shimazaki N, Sator, S, Miyamoto T, Akagawa H, Tsujimura K. The effect of mixture formation on the

combustion of premixed lean diesel. SAE Paper 980533; 1998.
20. Hashizume T, Miyamato T, Akagawa H, Tsujimura K. Combustion and emissions characteristics of multistage diesel combustion. SAE Paper 980505; 1998.
21. Odaka M, Suzuki H, Koike N, Ishii H. Finding an optimization method for homogeneous charge diesel combustion. SAE Paper 1999-01-0184; 1999.
22. Shi Lei, Deng Kangyao, Cui Yi, Qu Shuan, Hu Wei, Research on Knock Combustion of Negative Valve Overlap Injection HCCI Diesel Engine, Fuel 106 (2013) 478-83.
23. Berntsson AW, Denbratt I. Combustion of HCCI using charge stratification for combustion control. SAE paper 2007-01-0210; 2007.
24. Aroonsrisopon T, Werner P, Waldman JO, Sohm V, Foster DE, Morikawa T, Extending HCCI operation by charge stratification. SAE Paper 2004-01-1756; 2004.
25. S.V. Kandal, N.R. Banapurmath, V.N. Gaitonde. Performance studies of homogeneous charge compression ignition (HCCI) engines powered by alternative fuels. Renewable Energy, 132 (2019) 683-93.
26. N.R. Banapurmath, B.M. Damani, S.V. Khandal, S. S. Hiremath, V.B. Dual fuel (DF) engine with homogeneous charge compression ignition (HCCI) operating on compressed natural gas (CNG) and extended methyl ester (UOME) Mathematics, comparison between engines. Global Journal of Renewable Energy, PaperSciences Research Publisher, 2 (2014), 32-44.
27. S.V. Kandal, N.R. Banapurmath, V.N. Gaitonde, S.S. Hiremath, A Paradigm Shift in Advanced Injection Strategies from Mechanical Direct Injection Diesel Engines to Diesel Homogeneous Charge Compression Ignition (HCCI) Engines - Comprehensive Review, Renewable and Sustainable Energy Review 70, (April 2017) 369-384.
28. S.V. Kandal, N.R. Banapurmath, V.N. Gaitonde, A Performance Study of a Homogeneous Charge Compression Ignition (HCCI) Engine Powered by Alternative Fuels, Renewable Energy, Vol. 132, March 2019, 683-693,
29. S. B. Nagesh, N. R. Banapurmath, T. K. Chandrashekhar, S. V. Khandal, Experimental Study of Diesel and Biodiesel Manifold Injection in HCCI Engines with Charge Heating, European Journal of Sustainable Development, Research, October 2018, 2(4), 45, ISSN: 2542-4742.
30. Yunus Khana T.M., Atabanib A.E., IrfanAnjum Badruddina, Ankalgi R.F., Mainuddin Khan T.K, Ahmad Badarudin, 'CeibaPentandra, Nigella sativa and their blends as potential feedstocks for biodiesel', 'Industrial crops and products', 65 (2015), 367 –373.
31. Silitonga A.S., Ong H.C., Mahlia T.M.I., Masjuki H.H., Chong W.T., 'Characterization and production of CeibaPentandra biodiesel and its blends', Fuels, 108 (2013), 855-858.
32. S. Rajesh, B. M. Kulkarni, S. Kumarappa, N. R. Banpurmath, Influence of Injection Parameters on Performance and Emissions Characteristics of CRDi Diesel Engines Using Sour Oil Biodiesel-Ethanol Blend Fuel, Biofuels, Taylor and Francis Publications, vol. 9 , Jan 2017 - Issue 3, pp. 353-367.
33. M. Kalil Rahiman, R. Venkatachalam, and N. Nedunchezhian, Experimental Study of Thermal Barrier Coated Diesel Engines Fueled on Diesel-Biodiesel-Ethanol-Ether Blends, Journal of Renewable and Sustainable Energy 5, 033114 (2013); https://doi.org/10.1063/1.4808052.
34. James P. Szybist and Bruce G. Bunting, Effect of Cetane Number and Engine Speed on Diesel HCCI Performance and Emissions, October 2005 SAE Technical Paper, 10.4271/2005-01-3723.