Studies on the performance and exhaust emission characteristics of a plastic oil fueled CRDI engine with variable compression ratio

Swaraj Kumar Swain, Gunjit Rawat, K Suresh Kumar, G Balaji*

Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur-603203, Tamil Nadu, India

*Corresponding author email: balajig@srmist.edu.in

Abstract: In the modern days, the entire world is experiencing the sudden rise in energy needs. Strict emission rules and exhaust of oil reserves have led the scientists around the world to look into different fuels for IC engines. On other context, plastic wastes are currently the biggest problem across the globe for their indispensable nature and the alarming increase in the use of plastic for industrial applications. In this context, plastic oil has been considered as an alternative to the fossil fuels, as the properties of the oil extracted from waste Polyethylene are at par with those of diesel. Literature review reveals the fact that automobile sector ranks highest in polluting the environment through the emission of CO, CO₂, NOx and unburnt hydrocarbon. In the present work, an investigation has been carried out to convert the waste plastic into a combustible oil and use of this oil blended with diesel to run a 4-stroke, 3.5kW, single cylinder, CRDI engine. Plastic oil has been prepared by pyrolysis process and subjected to fractionation distillation. A blend consisting of 10% of this oil and 90% of diesel has been used as the fuel to run the engine at three different compression ratios. The performance and emission characteristics of the engine have been analyzed and reported. The results reveal a marginal increase in BTE, CO₂, NOx and decrease in BSFC, CO, HC and smoke emissions.

Key words: Plastic Oil, CRDI, Compression Ratio, Performance, Emission.

1. Introduction

CRDI engine can take higher fuel injection pressure through rail solenoid valve, which is oppose to the less pressure of normal mechanical injection fuel pump. If there is high pressure apply on the injection it produce the power and the lower pressure is applied on the injection process by injecting the small droplets of fuel it get the benefits of fuel consumption, due to this small droplets it gives ratio of surface area to volume. Because of this complete combustion get happen by the proper air fuel mixture in the combustion chamber and the vaporized part from the surface of droplet [1]. The most modern fuel engine system which is known as CRDI engine and it also called Common rail direct injection engine. In this we are using the diesel fuel for completing the study and this diesel fuel get supply forwarded to the fuel injectors and all diesel engine manufactures use the CRDI technology on comparison to petrol engine it has gasoline direct injection. The design and the working principle of this two type of technology is very much same it consist of fuel rail and then fuel further supplies to the fuel injector. Their parameters are different from each other such as pressure and different type of fuel, blended fuel get use in this technology. In this CRDI system the combustion
happened in the combustion chamber which get seen into the cavity of piston from TDC to BDC. Now a days the sum is solving of conventional diesel engines by this CRDI technology. These engines fitted in the passenger vehicles gives greater performance and lessen noise of the engine [2]. The working principle of this engine is governed by engine control unit which inject the fuel in injectors mechanically and electrically. Performance and emission was investigated for various compression ratio along with various fuel injection pressures fuelled with Jatropha methyl ester. It is found that the combined effect of increase in compression ratio and injection pressure is to increase the BTHE and reduce BSFC and the exhaust emissions [3].

The effect of injection parameters like injection pressure and injection duration on the performance and emissions of a common rail direct injection system assisted diesel engine has been evaluated using central composite design (CCD). Hike in brake thermal efficiency and appreciable reduction in fuel consumption were recorded due to better atomization [4]. High fuel and pilot injection pressures simultaneously reduces NOx emission by 35% and smoke emission by 60 to 80%, without adverse effect on fuel economy. The study revealed that reduction in ignition delay does not lead to notable improvement at usual injection timings before TDC. However, with considerable retardation in the injection timing or with a relatively long original ignition delay, shortening of ignition delay is effective in reducing premixed combustion, leading to reduced NOx emissions. In the CRDI system, post-injection occurs after the main injection, while the combustion is still on. Use of post injection re-ignites the soot particles which results in 20 to 70% reduction in soot emissions [5]. Unwanted plastic pyrolysed fuel mixture was tested in CRDI system with many injection pressures. They found 600 bar pressure provides improved brake thermal efficiency at full load settings for 15PDB fuel mixture [6]. Diesel-tung oil-ethanol fuel mixture was tested with various injection types in the CRDI system. They found combustion period got reduced, combustion pressure and HRR got increased. Performance got increased [7]. Also CRDI device injects fuel right away into the combustion chamber. In older engines, the indirect injection machine injects gasoline into a pre-combustion chamber, which in turn feed it to the combustion chamber [8]. Emission from any CRDI engine is consider to be undesirable, as they have negative and adverse effects on global warming, quality of air and human health. Various governments are experimenting with different schemes to control them. In India as the transportation activity is on the rise, use of any alternate fuel with the intension of emission reduction is inevitable.

2. Experimentation

![Photographic view of CRDI engine](image-url)
The device-setup includes a 3.5 kW, four stroke, CRDI VCR engine. Rotameter is provided for the measurement of cooling water flow. Variable compression ratio is used in the present study to investigate the influence of variation in CR on engine performance and emissions. The photographic view of the test engine is shown in figure 1. The gas analyser used in this experimental investigation is of AVL make Digas 444 model. This device is capable of measuring predominant exhaust emissions such as CO, CO₂, HC and NOx. Smoke meters are commonly used to detect and quantify the amount of light blocked in smoke emitted during the operation of diesel engines. Smoke meter readout shows the smoke density, highlighting the degree of performance of combustion. The smoke meter used is of AVL make. The fuel used for the experimentation is the plastic oil which is produced basically by two process fractional distillation method and plastic pyrolysis to get pure form of plastic oil. A blend of plastic oil and diesel has been used as the fuel. Plastic oil has been prepared and blended with diesel in the volume fraction of 1:9 with a magnetic stirrer. This blend has been used as the fuel to run the engine under variable load conditions. The investigation has been carried out at diverse compression ratio (CR) starting from 19 to 21. At each compression ratio (CR), load on engine has been elevated from 0 to 12 kg with the incremental of 3 kg and the data corresponding to engine performance and emissions were recorded.

3. Results and Discussion

3.1 Performance Analysis of CRDI Engine

The variation in brake thermal efficiency and brake specific fuel consumption with respect to load has been studied under three different CR values.

The variation in brake thermal efficiency (BTE) with brake power under three different CR values is depicted in figure 2. The value of BTE increased with the corresponding increase in BP at all load conditions. At all load conditions the BTE is found to increase with increase in the compression ratio. Increase in CR results in increased temperature, pressure and decrease in delay period leading to fast ignition of fuel and production of more power in quick time. Increase in CR also ensures complete combustion of fuel, injection of fuel at elevated temperature and pressure, resulting in rapid air-fuel mixing and rapid evaporation [9].

![Figure 2. Variation of Brake thermal efficiency](image)

The variation in brake-specific fuel consumption (BSFC) with respect to BP at different CR values is provided in figure 3. As seen from the graph, the BSFC keeps decreasing with increase in BP at all CR values. This variation is in good agreement with that of BTE. At low load conditions, the value of BSFC is...
very low for CR 21 as compared to CR 20 and CR 19. The decrease in BSFC with increase in CR is due to better atomization of fuel, air-fuel mixing at higher temperature and pressure, leading to improved combustion [10]. However at higher load conditions, the decrease in BSFC is not much appreciable for CR 21.

![Figure 3. Variation of BSFC](image)

### 3.2 Emission Analysis of CRDI Engine

In this section the effect of increase in CR value on various exhaust emissions like HC, CO, CO₂, NOx and smoke is analyzed.

Figure 4 highlights the variation of HC emission with respect to B.P for different CR values. It is evident that with increase in B.P, there is corresponding increase in the emission of HC. However the emission is found to decrease with increase in CR value at all load conditions. Higher CR value results in rapid fuel atomization and shorter injection, leading to better combustion and reduced HC emissions [11].

![Figure 4. Variation of HC emission](image)
The influence of increase in CR on the emission of CO is highlighted in figure 5. This emission is very low at lower load conditions and found to increase with increase in load. However increase in CR value resulted in decreased emission at all loads. This is due to the improved combustion of fuel, owing to very high air temperature inside the cylinder and drop in delay period.

Figure 5. Variation of CO emission

Figure 6 clearly depicts the variation of NOx with B.P for different CR values. The reason for NOx emission is sufficient gas temperature inside the cylinder to oxidize nitrogen present in air to NOx gases. This emission is found to increase with increase in CR value. It is obvious that higher the CR, higher will be the combustion temperature inside the cylinder and NOx formation. This increase in NOx formation with increase in CR value is noted at all loads.

Figure 6. Variation of NOx emission
As seen from figure 7, the emission of Carbon Dioxide is found to increase with corresponding increase in CR value. At very low load conditions, the emission level is not showing remarkable change with increase in CR. However at higher loads, the increase in emission with increase in CR is much appreciable. Higher the CR value, higher will be the cylinder peak pressure and temperature. Higher temperature and pressure inside the cylinder are responsible for the formation of higher valance oxygen atoms, which oxidizes CO into CO$_2$.

![Figure 7. Variation of CO$_2$ emission](image)

The variation of smoke emission with B.P for different CR values is highlighted in figure 8. Smoke is found to decrease with increase in CR value and the emission level keeps increasing with load for all CR values. When the Compression Ratio gets soar, the start of mixing of fuel to air become better in the course of ignition delay period and prone to absolute combustion. Better combustion at elevated CR emits limited smoke.

![Figure 8. Variation of Smoke emission](image)

4. Conclusion

Experimental investigation has been carried out to study the performance and emission of CRDI engine fueled with a blend of 90% diesel and 10% plastic oil under three different compression ratios i.e., 19, 20, 21. The following conclusions are made:
• CRDI engine fueled with plastic oil blended diesel at CR 21 performed well with better fuel efficiency compared to CR 20 and CR 19
• In case of performance analysis, the BTE increases at an average of 3.035% and BSFC decreases at an average of 3.83% on increment of Compression ratio. Therefore, it is concluded that with the increase in compression ratio (CR) the brake thermal efficiency (BTE) increases and specific fuel consumption (SFC) decreases with improvement in brake power (BP) in the plastic oil blended diesel fueled CRDI engine
• In case of emission analysis, gas pollutants such as HC, CO, Smoke emission were decreasing at the rate of 5.61%, 3.63%, and 4.12% respectively at each increment of compression ratio. However few gas pollutants such as NOx, CO₂ emission were increasing at the rate of 4.62% and 1.003% respectively at each increment of compression ratio.

References
1) Avinash Kumar Agarwal, Paras Gupta, Atul Dhar, “Combustion, performance and emissions characteristics of a newly developed CRDI single cylinder diesel engine”, Sadhana (2015), 40, 1937-1954.
2) C. Syed Aamal, C.G. Sarvanan, “Effects of nano metal oxide blended Mahua biodiesel on CRDI diesel engine”, Ain Shams Engineering Journal, (2015), 8(4). DOI:10.1016/j.asej.2015.09.013.
3) S. Jindal, B.P. Nandwana, N.S. Rathore , V. Vashistha, “Experimental investigation of the effect of compression ratio and injection pressure in a direct injection diesel engine running on Jatropha methyl ester”, Applied Thermal Engineering (2010), 30, 442–448.
4) G.Balaji and M.Cheralathan. Experimental investigation of varying the fuel injection pressure in a direct injection diesel engine fuelled with methyl ester of neem oil. International Journal of Ambient Energy (2017); 38: (4), pp 356-364.
5) Shundoh, S., Komori, M, Tsujimura, K., and Kobayashi, S., “NOx reduction from diesel combustion using pilot injection with high pressure fuel injection”, SAE Technical Paper 1992, 920461.
6) 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.
7) 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.
8) B.Sachuthananthan, G.Balaji and R.L.Krupakaran. “Investigation on the use of plastic pyrolysis oil as alternate fuel in a direct injection diesel engine with titanium oxide nanoadditive”, Environmental Science and Pollution Research (2019), 26, 10319-10332.
9) G.Balaji, Utkarsh Arora, Saurav Dasgupta and Siddhant Mund, “Individual effects of antioxidant additive and SCR system on the NOx reduction of a CI engine powered by cottonseed oil blend”, Material Research Express, (2019), 6, 085540.
10) G.Balaji and M.Cheralathan. “Experimental reduction of NOx and HC emissions in a CI engine fuelled with methyl ester of neem oil using p-phenylenediamine antioxidant”, Journal of Scientific & Industrial Research, (2014); 73, (3), 177-180.
11) G.Balaji and M. Cherilathanan. “Influence of alumina oxide nanoparticles on the performance and emissions in a methyl ester of neem oil fuelled DI diesel engine”. Thermal Sciences,( 2017), 21(1B), 499-510.