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Research Article

Experimental Studies on a DI-CI engine using blends of diesel fuel with Plastic diesel derived from Plastic Waste at 250 bar injection pressure

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Abstract

Replacement (partial) of fossil fuels with alternate fuels has been set as a target worldwide to reduce greenhouse effect and energy dependence as well as to improve economy. Emissions from transportation engines are considered to greatly contribute to greenhouse gases (carbon dioxide) release. In the present day scenario emissions associated with the exhaust of automobiles resulting in global warming is a major menace to the entire world and also detrimental to health. An experimental investigation is conducted to evaluate the use of Plastic diesel derived from plastic waste in a direct injection (D.I), C.I engine. The tests are conducted using each of the petrol diesel and Plastic diesel at 250 bar fuel injection pressure, with the engine working at Constant speed. Fuel consumption, and exhaust regulated gas emissions such as nitrogen oxides, carbon monoxide and total unburned hydrocarbons are measured. The differences in the measured performance, combustion and exhaust emissions from the baseline operation of the engine, i.e., when working with petrol diesel fuel and the plastic diesel are determined and compared. The experimental results show that blends of plastic diesel, with diesel lowers the viscosity and leads to good improvement in brake thermal efficiency.

Keyword: *Plastic diesel, Combustion, Emission, Neat diesel*

1. Introduction

Automobile emissions are increasing day by day and there is catastrophic future in respect of human health degradation. The emission regulatory boards are imposing stringent rules in controlling emissions worldwide. The population of fossil fuel run vehicles is increasing in multifold every year leading to peak pollution levels. Research round the globe is focused on the ways to reduce regulated and unregulated tail pipe emissions. Regulated emissions like NO_x, HC and CO emissions are important ones to be contained. Therefore, the need for reducing/minimizing emission levels of NO_x, HC, CO etc drawing attention of many a researcher. This can be achieved either by switching over to renewable fuels or by any other method which do not invite major changes in the design aspect of the engine in use which entails additional expenditure. Rudolph Diesel (Diesel.R, 1897) stipulated as a condition of his rational heat motor that fuel must be introduced gradually so as to maintain an isothermal combustion process.

Hence, from the early days of diesel engine development, it appeared that diffusion burn combustion would dominate. Nevertheless, this developmental road progressively changed direction as awareness of vehicle emissions and their impact on the atmosphere surfaced (Haagen-smit et.al., 1955).As researchers learned more about diesel engine combustion, it became increasingly clear that the diffusion burn portion was largely responsible for its soot emission (Khan.I,1969). Therefore, the desire to overturn Diesel's condition of isothermal combustion developed, and attention shifted to premixed combustion modes (Lechner.G, 2003). Today, the development of combustion strategies resembling homogenous charge compression ignition (HCCI) strategies is vigorously pursued. The promise of simultaneously reduced NOx and Particulate Matter (PM) offers attractive incentives, especially considering the associated minor penalties in fuel economy. The popular press has become excited at the prospects of HCCI-type combustion systems, which are viewed as the internal combustion engine's best response to future competition from fuel cells and hybrids (Shirouzu.N, 2004). Much of the developmental strategies and targets are dictated by ever stringent emissions standards on passenger vehicles. The second alteration is a redesign of the piston bowl to reduce cylinder compression ratio from 19:1 (production compression ratio) to 16:1 (Takeda.Y et.al,1996). This reduction in compression ratio reduces the pre-injection thermodynamic state, resulting in increased ignition

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delays. The increased ignition delay increases the time for fuel and air mixing, allowing for attainment of premixed compression ignition combustion EPA started imposing air emission regulations on heavy duty engines in 1985, to take effect in 1991, and then more stringent regulations in 1994. However, these initial regulations could be met with optimized combustion strategies, and improved combustion chamber design. This work examines the interactions resulting from the application of a plastic diesel derived from plastic waste on a practical heavy-duty diesel engine system, with the aim of understanding their impact on emissions and performance. The goal of this experimental study is to assess the new fuel contributions to potential performance and efficiency penalties. Plastic diesel itself is a waste by product known to reduce the serious pollution threat to all most all the nation's worldwide. An attempt is made to assess the combustion and performance phenomenon of plastic diesel fuel. Some tests were conducted with the neat diesel application to verify the delineation line to fix up the performance of the diesel engine designed for diesel fuel. Marginal changes in the performance in the wise of SFC and BSFC cannot decipher the nature of combustion exactly. That is the reason why an extensive investigation encompassing the performance, emissions is taken up to evaluate the engine under the new conditions of the fuel implementation. The merits and the demerits of the plastic diesel fuel implementation with the neat diesel application are discussed. The fuel in the form of liquid hydrocarbons derived from plastic waste constitutes approximately 80% of total *post-consumer* plastic waste in India and includes PET, LDPE, PVC, HDPE, PP, PS etc. into liquid fuel oil. The process adopted is based on random de-polymerization of waste plastics in presence of a catalyst into liquid fuel (Mangalorean, Tribute India&Plastic2petrol Online). Fractional distillation was carried out by the author at his laboratory to convert the liquid hydro carbons to plastic diesel fuel at a temperature from 160^0 c to 260^0 c as suggested by the inventor and a dark yellow color diesel like fuel (PD) is derived by distillation with an approximate yielding of 30%. The distillation set up and the derived fuels are shown in the figure1.

Fig.1 Experimental Setup of Fractional Distillation to Extract Plastic Diesel (PD) from Liquid Hydro Carbons Derived From Waste Plastic

2. Experimentation

2.1 Experimental Setup

Direct Injection, Diesel engine is utilized for the experimentation. Experimentation is carried out at various engine loads to record the cylinder pressure and finally to compute heat release rates with respect to the crank-angle. Engine performance data is acquired to study the performance and engine pollution parameters.

Table 1 Specification of DI-Diesel Engine

Rated Horse power: 5 hp (3.73 kW)
Rated Speed: 1500rpm
No of Strokes: 4
Mode of Injection :Direct Injection
Injection pressure :200 bar
No of Cylinders:1
Stroke :110 mm
Bore :80 mm
Compression ratio:16.5:1

The smoke values in HSU, the exhaust gas temperatures and exhaust gas analysis of different components of exhaust gas are measured and compared and engine performance is analyzed for the parameters mentioned above with the implementation of blends of petrol diesel with plastic diesel and with the blend of plastic diesel with cetane improver.

2.2 INDUS PEA 205, (Exhaust Gas Analyzer)

Fig. 2.1 INDUS PEA 205, Exhaust Gas Analyzer

The PEA 205 shown in figure.2.1 measures the exhaust emission such as Carbon Monoxide (CO), Carbon Dioxide (CO_2), Hydro Carbon (HC), Oxygen (O_2) and

Nitric Oxide (NOx) by means of Non-Dispersive infrared (NDIR) measurement.

2.3 Experimental Procedure

The experimentation is conducted on a single cylinder direct injection diesel engine operated at normal room temperatures of 28^{0}C to 33^{0}C The experiment was done with fuels diesel like fuel derived from plastic waste (PD) and Plastic Diesel fuel mixed with cetane improver(PDCI), Diesel oil in neat condition(ND) as well as with 20%, 40%, 60% and 80% blends of plastic diesel with petro diesel(PD20,PD40,PD60 and PD80) at five discrete part load conditions namely No Load, One Fourth Full Load, Half Full Load, Three Fourth Full Load and Full Loads at fuel injection pressure 250 bar shown in figure2.A.

Fig. 2.a Experimental Setup

The fuel consumption for the PD (PD100), PDCI, PD20, PD40, PD60, PD80 fuel runs and for the petrol diesel is measured at all defined loads both with U-tube manometer and fuel Rota meter. The heat release rate values are derived from the pressure- crank angle signatures by a suitable computer program.

3. Results

3.1 Performance analysis of Blends of Plastic Diesel with Diesel

On increase of injection pressure, the fuel droplet size will be decreased. When the droplet size decreases for the given quantity of fuel, the surface area will be increased and as a result the latent heat transfer rate from the compressed air in the compression stroke will be more. It results into better vaporization of fuel and leads to better combustion. At 250bar (fig.3), the brake specific fuel consumption for plastic diesel (PD100) is 0.4904 kg/kw-hr, whereas for diesel it is 0.2913 kg/kw-hr at full load, 40.59% difference is recorded. At plastic diesel-20, 250 bar the specific fuel consumption is 0.3790 kg/kw-hr which is only 7.365% higher than diesel consumption at 200 bar injection pressure.(J.Sudhir Kumar et.al,2011)

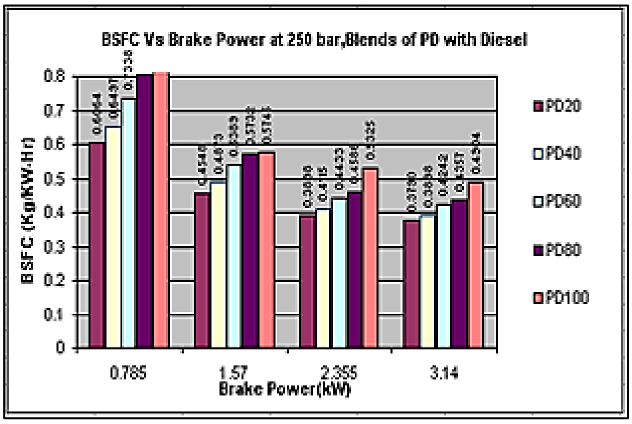

Fig.3 Brake Specific fuel Consumption V/s Brake power graph at 250bar Pressure with Blends of Plastic Diesel with Diesel at full load

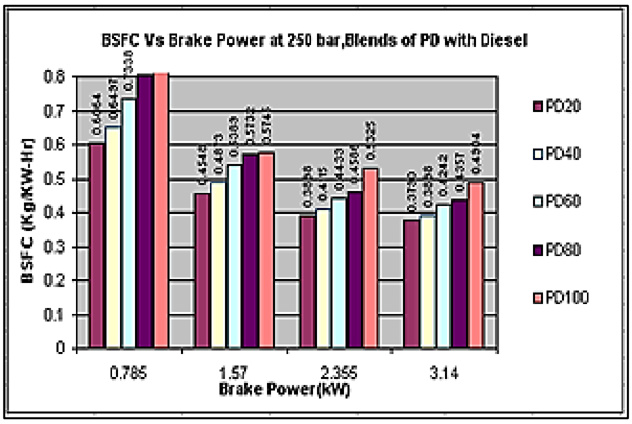

Fig.4 Brake Thermal Efficiency V/s Brake power graph at 250bar Pressure with Blends of Plastic Diesel with Diesel at full load

The brake thermal efficiency is 20.32% for the plastic diesel-100(PD100) at 250 bar injection pressure (fig.4). The brake thermal efficiency gradually decreases from plastic diesel-20 to plastic diesel-100. Brake thermal efficiency at plastic diesel-20 is 26.29%, brake thermal efficiency for the petro diesel is 26.55% at 200 bar injection pressure. There is negligible variation in brake thermal efficiency. It shows better conversion of thermal energy in to mechanical work on increasing of injection pressure.

3.2 Combustion Analysis

3.2.1 Combustion analysis of Blends of Plastic Diesel with Diesel

On increase of injection pressure the peak pressure raise is shifted nearer to the TDC. But the delay period is 20^0 of crank angle in case of plastic diesel shown in figure 5 and peak pressure obtained is 90 bar and it is occurred at 372^0 of crank angle. But for the blends of plastic diesel on increase of pressure to 250 bar, delay period decreased and it is about 10^{0,} for PD-80 and for all other cases it is around 8^0. Plastic diesel-20 shows a uniform pressure rise and the peak value of it is 97.4 bar, which is occurred at 362^0 crank angle and it is very near to the TDC. Plastic diesel-60 also shows the similar trend, but fluctuations are high. The position pressure gradually moves away from the TDC in plastic diesel-20to plastic diesel-100(PD). This shows the delayed combustion. Figure 6 shows the heat release rate during the combustion at 250 bar injection pressure. In this graph also diesel and plastic diesel-20 shows the uniform heat combustion with less fluctuations. But on increase of percentage of plastic diesel, fluctuations in combustion are increased. 100% plastic diesel still shows the non-uniform heat release during the combustion. The maximum heat is released below 400^0 of crank angle.

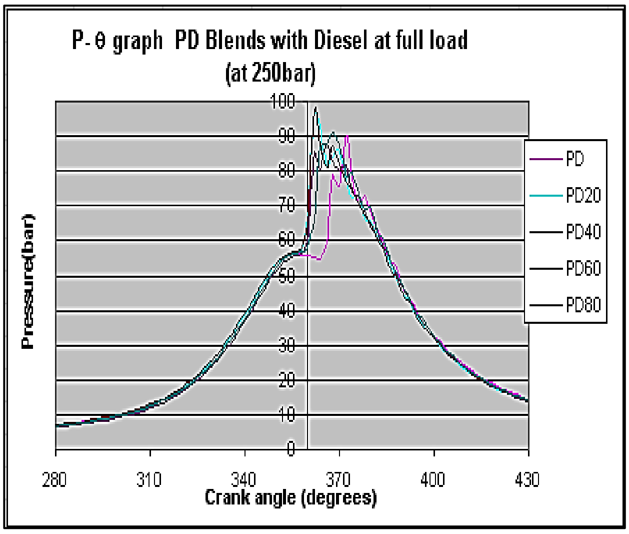

Fig. 5 P-θ Graph at full load with Blends of Plastic Diesel with Diesel, at 250bar Pressure

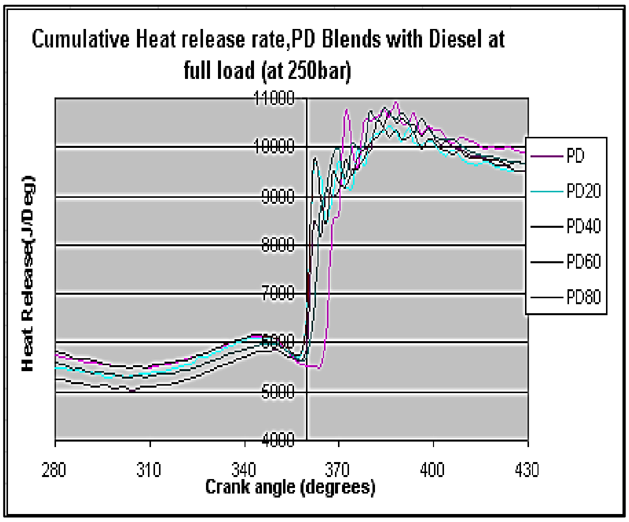

Fig. 6 P-θ Graph at full load with Blends of Plastic Diesel with Diesel, at 250bar Pressure

3.2.2 Analysis of Emission Parameters of Blends of Plastic Diesel with Diesel

On increase of injection pressure to 250 bar, the peak pressure rise moves towards the TDC. The combustion duration is also more and the same can be observed from the p-θ and HRR diagrams. As a result most of the thermal energy efficiently converted into useful mechanical work. It supported by increasing of thermal efficiency on increasing of injection pressure. Figure 7 shows exhaust gas temperatures at different blends. The variation of EGT at particular load for different blends is negligible. But when compared with the temperatures at 200 bar injection pressure, these temperatures are low. Around 273^0 C drop in temperature for plastic diesel operation from 200 bar injection pressure to 250 bar injection pressure at full load is observed. Corresponding drop in formation NOx can also be observed from the Figure 8.The drop in NO_x is around 15.7% with respect to NO_x at 200 bar injection pressure. At plastic diesel-20 the drop in NO_x is negligible. On increase of injection pressure the rate of reaction in between hydrocarbons of fuel and the oxygen increases. The portion of the fuel burnt also gets increased. It leads to decrease in HC and CO at 250 bar injection pressure. This can be observed from figure 9 or figure 10.

There is no much variation of CO_2% (figure 11). Smoke also shows the same trend as it shown at 200 bar injection pressure (figure 12).(J.Sudhir Kumar et.al,2011).

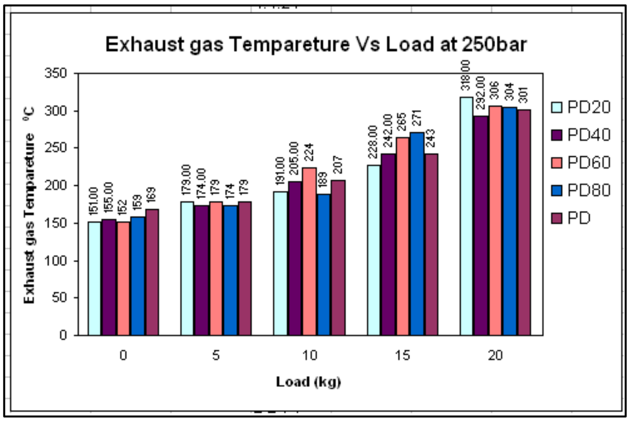

Fig. 7 Exhaust Gas Temperature V/s Load graph with Blends of Plastic Diesel with Diesel, at 250bar Pressure

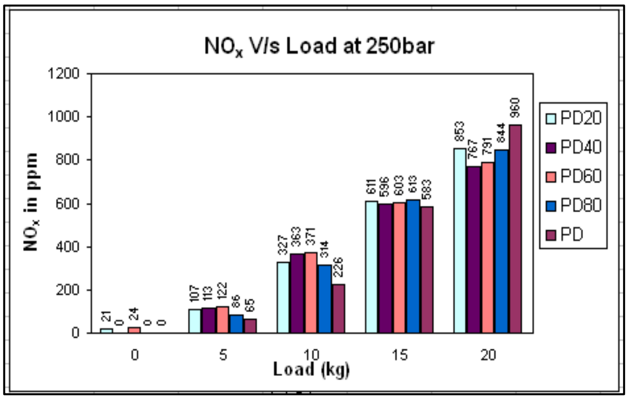

Fig. 8 Nitric Oxide V/s Load graph with Blends of Plastic Diesel with Diesel, at 250bar Pressure

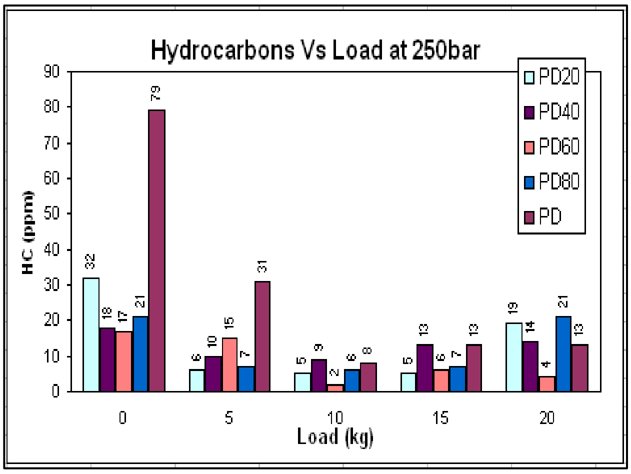

Fig.9 Hydro carbons V/s Load graph at 250bar Pressure with Blends of Plastic Diesel at 250bar Pressure at full load

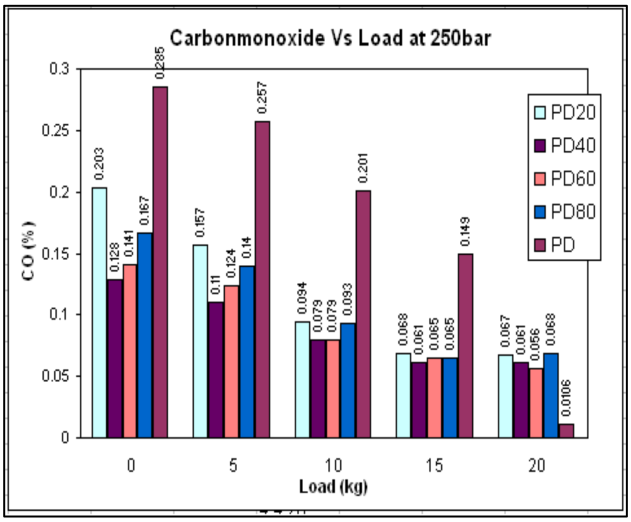

Fig.10 Carbon Monoxide V/s Load graph with Blends of Plastic Diesel with with Diesel Diesel at full load

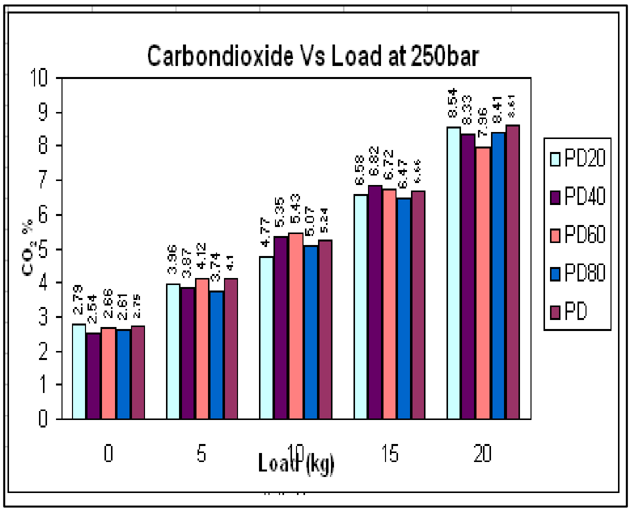

Fig. 11 Carbon dioxide V/s Load graph with Blends of Plastic Diesel with Diesel, at 250 bar Pressure

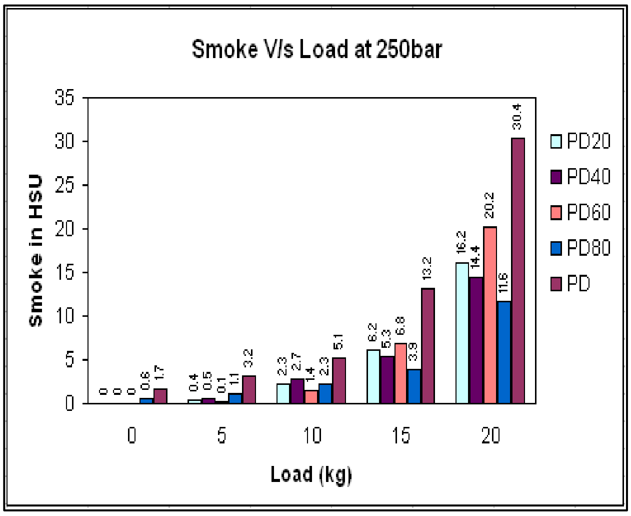

Fig. 12 Smoke Value V/s Load graph with Blends of Plastic Diesel with Diesel, at 250 bar Pressure

3.2.3 Performance analysis of Plastic Diesel with Cetane Number Improver

At 250bar Pressure, "Performance analysis" of Plastic Diesel with Cetane Number Improver: The cetane number improver decreases the delay period (chemical), and increase in the injection pressure improve the particulate size, as a result the homogenization and vaporization gets improved. As a result of better combustion SFC gets decreased and brake thermal efficiency is improved. Figure 13 shows the SFC with respect to B.P at 250 bar injection pressure. The decrement of SFC due to CI is negligible at part load and full load operations but SFC values are slightly less than the 200 bar operations (J.Sudhir Kumar et.al,2011).Similarly in the case of the brake thermal efficiency (figure 14) also negligible improvement can be observed. The brake thermal efficiency at 250 bar pressure for PDCI at full load is around 21%.

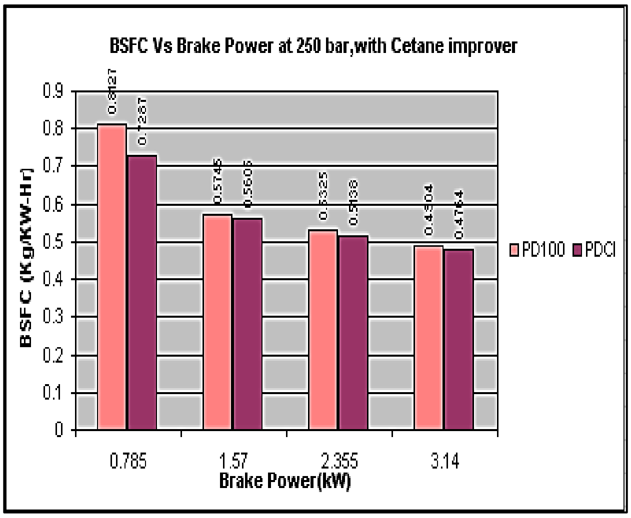

Fig.13Brake Specific Fuel Consumption V/s Brake Power Plastic Diesel with Diesel, at 250bar Pressure

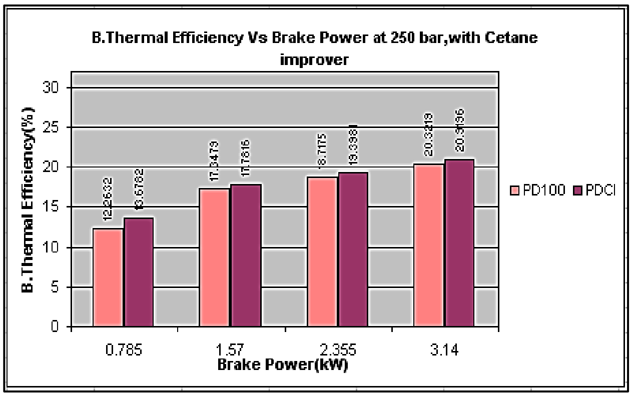

Fig.14 Brake Thermal Efficiency V/s Brake Power graph with blends of with blends of Plastic Diesel with Diesel, at 250 bar Pressure

3.3 Combustion Analysis with Cetane Improver:

3.3.1 Combustion Analysis of Plastic Diesel with Cetane Number Improver

The results at 250 bar injection have not shown any decrement in the delay period, but the peak pressure and the heat release rate are low at this condition figure 15 and figure 16.

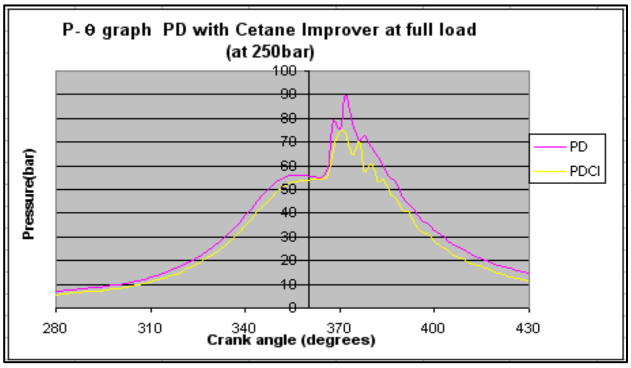

Fig.15 P-θ Graph at full load, Plastic Diesel with Cetane Number Improver, at 250 bar Pressure

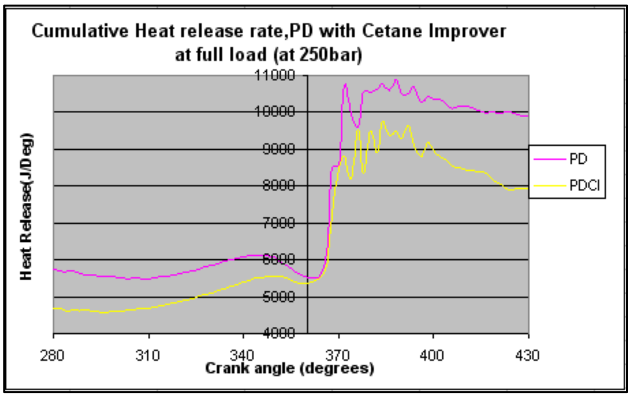

Fig.16 Cumulative Heat Release Rate Vs Crank Angle graph, at full load, Plastic Diesel with Cetane Number Improver, at 250bar Pressure

3.3.2 At 250bar Pressure, Analysis of Emission Parameters of Plastic Diesel with Cetane Number Improver

At 250 bar injection pressure with PDCI, further decrement of delay period and droplet size lead to quick and complete combustion. As a result the premixed combustion zone is reduced and exhaust gas temperatures are lowered. EGT at particular load at 250 bar has no significant variation (figure 17).

But when it is compared with 200 bar operation around 200^0C, drop in temperature of the exhaust gas (figure18) shows the formation of NO_x at 250 bar operation. The formation of NO_x at 250 bar is slightly higher than 200 bar operation (J.Sudhir Kumar et.al, 2011). HC and CO are slightly higher at this operating condition figure 19 and fig. 20. CO_2 is slightly improved and smoke value is decreased further.(figure 21 and figure 22)

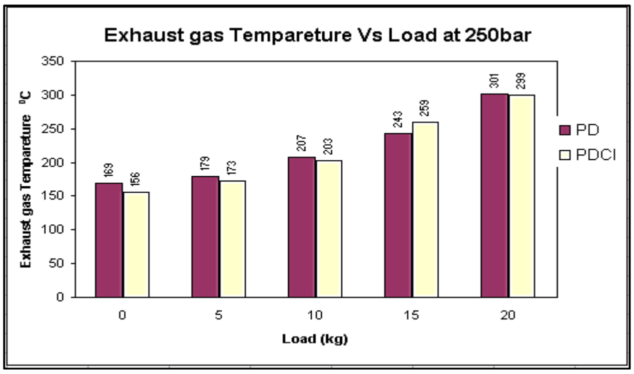

Fig.17

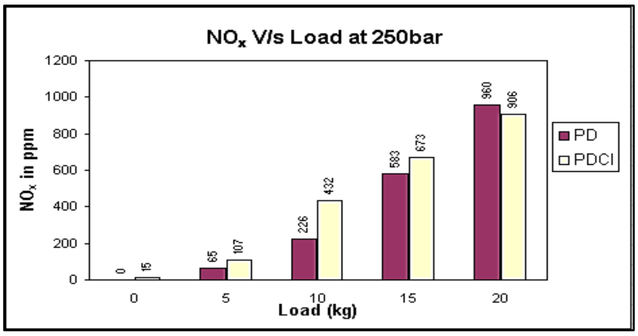

Fig.18

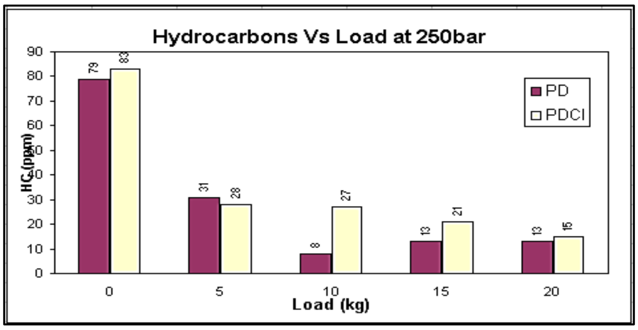

Fig.19

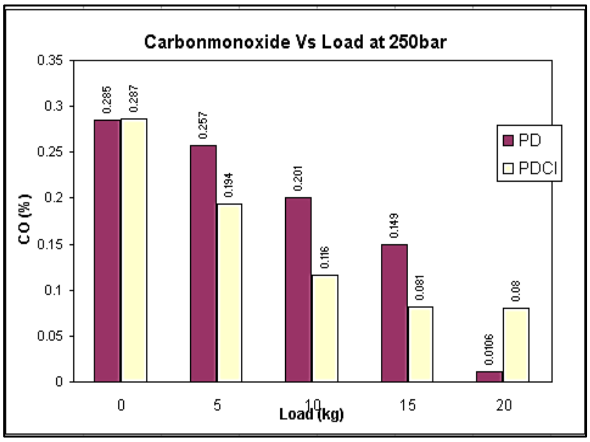

Fig.20

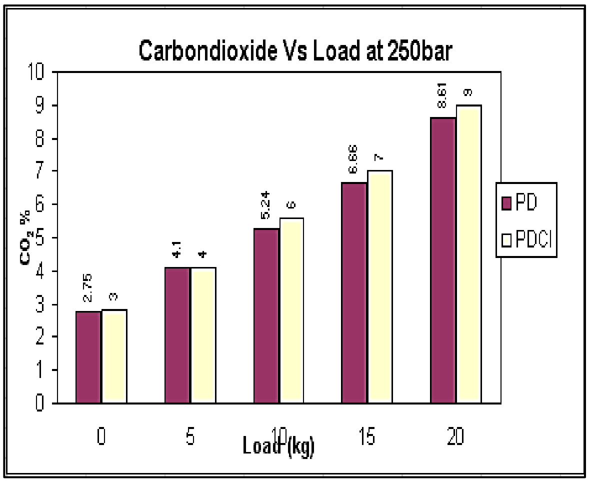

Fig.21

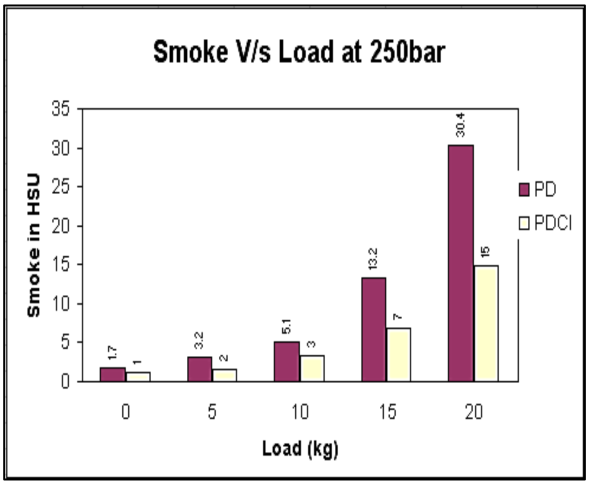

Fig.22

4. Conclusions

Direct implementation of plastic diesel at 200 bar injection pressure leads to poor B.S.F.C and Brake thermal efficiencies. It also caused for generation of higher amount of CO and HC in the exhaust gas and heavy deposits of carbon in the engine cylinder. The reasons for poor combustion quality of plastic diesel are higher viscosity and lower cetane number. Plastic diesel also contains higher amounts of sulphur which leads to acid rains. Blends of plastic diesel, with diesel lowers the viscosity and leads to good improvement in brake thermal efficiency. Plastic diesel-20 gives the 25.568 brake thermal efficiency at 200 bar injection pressure. The cetane number improver gives better ignition quality and PDCI gives uniform heat release during the combustion. As a result of adding of CI, the improvement in the brake thermal efficiency is very low, but it gives smooth burning of fuel.

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